

**GENETIC ANALYSIS OF HEIFER AND COW FERTILITY
FOR SOUTH AFRICAN HOLSTEINS USING
ARTIFICIAL INSEMINATION RECORDS**

by

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The crest of Stellenbosch University is centered behind the text. It features a shield with a red and white checkered pattern, a blue chief, and a red lion rampant. The shield is flanked by two red lions. Below the shield is a scroll with the motto "Pictura rubicundus cultus recti".

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Declaration

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Summary

Female fertility has gained significant attention in the dairy cattle industry and is increasingly being incorporated in to breeding objectives worldwide. In South Africa, genetic improvement of the trait is hampered by lack of sufficient data and the availability of estimated breeding values for traits indicating reproductive performance of dairy cows. Currently, only two traits, i.e. calving interval and age at first calving are used as indicators of fertility in the routine genetic evaluations of South African dairy cattle. The objective of this study was to derive alternative measures of heifer and cow fertility based on artificial insemination records, and estimate genetic parameters and breeding values, for their possible inclusion in the SA Holstein cattle breeding programs. A total of 64464 artificial insemination records from 18 South African Holstein herds were collected from an on-farm milk recording system. The dataset entailed information on birth date, service and calving dates of each animal, lactation number, pregnancy diagnosis statuses, dam and sire identification numbers from which heifer and cow fertility traits were defined. The following traits were defined: age at first service (AFS), number of services per conception for heifers (SPCh), the interval from calving date to first service date (CFS), number of days open (DO), the number of services per conception for cows (SPC) and binary traits indicating whether cows were inseminated within 80 days post-partum, whether cows were confirmed pregnant within 100 or 200 days open (FS80d, PD100d and PD200d). Statistical analyses of genetic parameters and breeding values were performed using THRGIBBSF90 and POSTGIBBSF90 of Blupf90 family of programs.

The heritability estimates obtained in this study were low to moderate (0.02 to 0.24), indicating that there is genetic basis for the explored fertility traits that warrants genetic selection. The genetic correlations between fertility traits observed in the current study were generally favourable with the highest correlations between CFS and SPC (0.90), AFS and AFC (0.91) and AFC and SPC (0.95). There were unfavourable correlations although very low between DO and AFS (-0.03), between AFS and SPCh (-0.06). Positive genetic correlations indicate that genetic improvement in one trait is coupled with a correlated increase in another. There was generally no distinct trends for heifer traits indicating that not much work was done in improving the traits. There were observed favourable genetic trends obtained for the cow traits, CFS with a decrease of 0.01 days/year and DO with a decrease of 0.06 days/year. However, increases were observed

in the phenotypic trends of CFS (0.16days/year) and DO (0.83days/year). The unfavourable and non-distinct trends indicates that there is a need for improving female fertility traits. Sufficient data recording and genetic evaluations are a pre-requisite for the incorporation of fertility traits in dairy cattle breeding programs towards the improvement of reproductive performance. The results from the current study shows that on farm artificial insemination records could be useful towards improving the fertility in South African Holstein cattle population.

Opsomming

In die melkbedryf kry die vrugbaarheid van melkkoeie tans hoe meer aandag en word wêreldwyd toenemend in teelt doelwitte ingesluit. In Suid-Afrika word die genetiese verbetering van koeivrugbaarheid bemoeilik weens 'n gebrek aan geskikte rekords en die beskikbaarheid van beraamde teelwaardes vir eienskappe wat die reproduksievermoë van melkkoeie aandui. Tans word slegs twee eienskappe, naamlik interkalfperiode en ouderdom met eerste kalf, in die jaarlikse genetiese ontledings vir Suid-Afrikaanse melkbeeste as 'n aanduiding van koeivrugbaarheid gebruik.

Die doel van die huidige studie was om alternatiewe vers- en koeivrugbaarheidsmaatstawwe, gebaseer op kunsmatige inseminasie rekords, af te lei en om genetiese parameters en teelwaardes te beraam vir die moontlike insluiting daarvan in teeltprogramme vir die Suid-Afrikaanse Holsteinras.

'n Totaal van 64464 kunsmatige inseminasie rekords van 'n kuddebestuurstelsel van 18 Holsteinkuddes was beskikbaar. Die datastel het bestaan uit rekords van geboorte- en dekdatums van koeie en verse, kalldatums van koeie, laktasienommers, die uitslag van dragtigheidstoetse, moeder en bul identifikasienommers. Hiervan is verskillende vrugbaarheidseienskappe vir koeie en verse afgelei.

Die volgende eienskappe is verkry: by verse: ouderdom met eerste dek (OED), aantal inseminasies per konsepsie vir verse (KIKverse), ouderdom met eerste kalf (OEK) en by koeie: die aantal dae van kalldatum tot eerste inseminasiedatum (KED), aantal dae oop (DO), the aantal inseminasies per konsepsie vir koeie (KIKkoeie) asook binêre eienskappe wat aandui of koeie geïnsemineer is binne 80 dae na kalf (EKi80d), en of koeie dragtig was binne 100 (PD100d) en 200 dae oop (PD200d).

Statistiese ontledings om genetiese parameters en teelwaardes te beraam is gedoen deur THRGIBBSF90 en POSTGIBBSF90 van die Blupf90-groep van programme te gebruik.

Die beraamde oorerflikhede wat in hierdie studie verkry is het gevarieer van laag tot matig (0.02 tot 0.24). Dit dui daarop dat die gedefinieerde vrugbaarheidseienskappe 'n genetiese basis het en dat genetiese seleksie moontlik is. Die genetiese korrelasies tussen vrugbaarheidseienskappe was oor die algemeen gunstig met die hoogste korrelasies tussen KED en KIKkoeie (0.90), OED en ouderdom met eerste kalf (0.91) en OEK en KIKkoeie (0.95). Hoewel baie laag, is ongunstige korrelasies tussen DO en OED (-0.03), tussen OED en KIKverse (-0.06) gevind.

Positiewe genetiese korrelasies dui daarop dat 'n genetiese verbetering in een eienskap gepaardgaan met 'n gekorreleerde verbetering in 'n ander eienskap. Daar was oor die algemeen geen duidelike tendense in vrugbaarheidseienskappe vir verse nie, wat daarop dui dat tot op datum geneties min gedoen is om eienskappe te verbeter.

Daar was gunstige genetiese tendense waargeneem vir sommige koei-eienskappe, naamlik vir KED 'n afname van 0.01 dae/jaar en vir DO 'n afname van 0.06 dae/jaar. Verhogings is egter waargeneem in die fenotipiese tendense vir KED van 0.16dae/jaar en vir DO van 0.83dae/jaar.

Die ongunstige en nie-ooglopende tendense dui daarop dat dit nodig is om vroulike vrugbaarheidseienskappe te verbeter.

Voldoende data-aantekening en die genetiese evaluering daarvan is 'n vereiste om vrugbaarheidseienskappe in teelprogramme vir melkbeeste in werking te stel ten einde die vrugbaarheid van melkkoeie te verbeter. Die resultate van die huidige studie toon dat kunsmatige inseminasie rekords wat op plaasvlak vir bestuursdoeleindes versamel word bruikbaar is om die vrugbaarheid in Suid-Afrikaanse Holsteinkoeie te verbeter.

This thesis is dedicated to my son Atlegang Kgari, for his unreserved love, understanding and always being a great inspiration for me to strive for more. It is a great honor to be your mother and your presence in my life is the most important part of my existence. I will always love you son.

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Preface

This thesis is presented as a compilation of 6 chapters. Each chapter is introduced separately and is written according to the style of the journal South African Journal of Animal Science (SAJAS) to which Chapter 2 was submitted for publication.

Chapter 1	General Introduction and project aims
Chapter 2	Evaluation of genetic aspects of dairy cattle fertility – A review
Chapter 3	Non-genetic factors affecting female fertility traits
Chapter 4	Estimation of genetic parameters, phenotypic and genetic correlations among defined service records for Holstein heifers and cows
Chapter 5	Estimation of breeding values, genetic and phenotypic trends for service based heifer and cow fertility traits of Holstein cattle
Chapter 6	General conclusions and recommendations

Notes

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Kgari, R.D. and Makgahlela, M.L. 2017. No fertile cow = No calf = No Milk. *The Dairy Mail*. 24:11. 100-103.

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CHAPTER 1

GENERAL INTRODUCTION

The productivity of any livestock species depends largely on the soundness of its reproductive performance. Fertility in dairy cows can be defined as the ability of cows to conceive earlier in the breeding season and deliver a viable calf. Profitability of a dairy enterprise is determined to a large extent by the reproductive performance of the herd, not necessarily by increasing milk production but by decreasing input costs of production. Additional expenses are incurred through repetition of artificial inseminations, extra hormonal treatments, and veterinary examinations of cows that are susceptible to diseases and outsourcing of replacement heifers. Economic losses incurred from poor fertility are also due to a loss of production because of prolonged calving intervals (Van Arendonk *et al.*, 1989; Olori *et al.*, 2002).

Calving interval of Holstein cows in South Africa (SA), increased from 386 in 1984 to 420 days in 2004 (Makgahlela, 2008). In the UK, calving interval lengthened from 370 to 390 days (Royal *et al.*, 2000a). Increasing calving intervals have a negative effect on the profitability of a dairy enterprise. Longer calving intervals have a negative genetic correlation with lifetime profit (-0.265) (Do *et al.*, 2013). A comparison of results from two trials in the UK showed that pregnancy rate to first service declined from 55.6 % to 39.7 % (Royal *et al.*, 2000a). There is also evidence of an unfavorable relationship between milk production and estrus behavior with shorter estrus periods (5.5 vs 11.1 h) in high (> 40 kg per day) relative to low (< 30 kg per day) producing cows (Lopez *et al.*, 2004). Several studies of the genetic relationships between fertility and production traits found that genetic correlations between milk yield and fertility traits were antagonistic and statistically significant (Grosshans *et al.*, 1997;

Makgahlela, 2008; Strucken *et al.*, 2012; Tenghe *et al.*, 2015). Higher milk yield is genetically correlated with longer calving interval, increased days to first service and reduced conception at first service (Pryce, 1998). Poor reproductive performance is the primary reason for involuntary culling in a dairy enterprise. A United Kingdom study calculated the value of a replacement heifer as R24 896.48 based on rearing costs while the value of a cull cow was found to be R12946.17 for a 600kg cow, indicating farm loses of R11950.31 in involuntary culling per cow per year (Lavern, 2017). Culling rates of poor reproductive performance were reported up to 25% in France (Colleau & Moureaux, 1999), 25.9% in Sweden (Ahlman *et al.*, 2011) and 21.27% in Iran (Ghaderi-Zhefreh *et al.*, 2017).

Fertility traits were previously excluded from selection indices as they were considered to be difficult to measure and exhibit lower heritability (Pryce *et al.*, 1998; Kadermideen, 2004). Fertility performance is influenced by environment (E), genotype (G) and the interaction between G by E (G x E). Despite the low heritability of fertility traits, sufficient additive genetic variation for fertility traits exist among dairy cattle populations to implement efficient selection programs. Dairy cattle genetic evaluations and selection decisions were focused primarily on production traits (Evans *et al.*, 1999; Pryce & Veerkamp, 2001). Milk yield has since doubled in the past 40 years with many cows producing up to 20 000kg per lactation (Oltenacu & Broom 2010). Genetics played a huge role towards increasing milk yield as animals went through intensive artificial selection however, sound management, good nutrition and other environmental conditions also contributed to the increased milk yields. Reproductive biotechnologies such as artificial insemination (AI) and embryo transfer also facilitated the widespread use of elite bulls and cows for production (Oltenacu & Broom, 2010).

However, with increasing milk yields, fertility has been declining (Pryce *et al.*, 2004; Oltenacu & Broom, 2010). This may be due to the antagonistic relationship that exists between production and fertility traits.

Nordic countries (i.e., Denmark, Finland and Sweden) were the first to implement health and fertility recording systems and incorporate these traits in the selection index (Philipsson and Lindhé, 2003; Wesseldijk, 2004). In Finland, recording for functional traits was established in 1982, and included in the total merit index for bulls in 1990. This was followed by Denmark and Sweden including health and longevity traits in selection indexes in 1996. In a survey performed in 2004, SA was one of the countries that only incorporated production and conformation traits in their selection index (Wesseldijk, 2004). South African dairy industry later adopted a Holstein Profit Ranking (HPR) index system that combines breeding values for five traits namely: milk volume, fat, protein, somatic cell count and calving interval, each included with an appropriate economic weighting relating to its overall contribution to profitability (Imbayarwo-Chikosi *et al.*, 2015).

Inclusion of calving interval in SA dairy cattle selection programmes is a positive move. However, as the only indicator of fertility, CI has several drawbacks. Amongst others, it depends on a subsequent calving date indicating its late availability, largely influenced by the breeder by extending lactation length for high producing cows and excludes heifers that calved only once or culled for not getting pregnant, (Olori *et al.*, 2002; Muller *et al.*, 2012). These factors could lead to biases in the estimation of breeding animals for improved female fertility. Additional selection criteria are required for the genetic improvement of female fertility in dairy cattle.

South African dairy farmers generally keep records of AI activities, and pregnancy diagnosis outcomes via automated milk recording systems for breeding and herd management purposes. Such information could be used to identify additional selection criteria for female fertility (Muller *et al.*, 2012). For example, the ability of the cow to come on heat early in the breeding season as defined by the days from calving to first service and whether the first service was performed within the first 80 days in milk. The second category would be fertility traits assessed by checking whether the cow or heifer can conceive from fewer or several AI services per conception. The use of service data in identifying additional selection criteria for genetic improvement of female fertility, as a functional trait, may accelerate the dairy enterprise economy and viability considering animal welfare issues and the environmental pressures experienced by this industry.

1.1 Justification

Female fertility of South African dairy cattle has been declining over the years with the increase in milk yield. The unfavorable genetic relationship between milk yield and reproductive performance is well-documented (Jonsson *et al.*, 1999; Haile-Mariam *et al.*, 2003; Dobson *et al.*, 2007; Ulutas & Sezer., 2009). Deterioration in reproductive performance reduced farm income due to involuntary culling where farmers had to rear or outsource more replacement heifers. These will have detrimental effects on the economics of our dairy industry if ignored. There is limited knowledge of reproductive performance of South African dairy herds (Potgieter, 2012), warranting the need for more research. Fertility traits are generally known to be lowly heritable i.e. 0.06 for days open (Eghbalsaied, 2011), 0.029 for calving interval (Rahbar *et al.*, 2016) and

0.15 for age at first calving (Zelege *et al.*, 2016). However, these traits have high additive genetic variation (Hermas *et al.*, 1987; De Jong, 1998) and therefore, increasing information that can be used in genetic evaluations may facilitate the improvement of fertility traits through selection. This study will compute estimated breeding values (EBV's), which are required for selection and for measuring genetic ability for fertility of heifers and cows.

The Agricultural Research Council (ARC)'s National Milk Recording and Improvement Scheme (NMRIS) for dairy cattle provides performance data recording services to SA dairy cattle farmers. The data collected under the NMRIS includes age at first calving and calving interval, hence genetic evaluations for fertility have been based on calving interval. Calving interval (CI) presents several limitations including the delay of breeding heifers, exclusion of heifers that fail to conceive and cows that do not have subsequent calving dates due to culling. This can lead to selection bias and nullify selection decisions. There is a need to identify fertility measures in addition to CI, for inclusion in selection programmes for improved female fertility in South African dairy cattle. This information could be obtained from on-farm automated milk recording systems that record AI services and pregnancy diagnosis outcomes.

1.2 Study objectives

Aim of the study

The aim of this study was to estimate genetic parameters and breeding values for heifer and cow fertility traits using AI service records in South African Holstein cattle, for future inclusion in breeding programs.

Objectives

1. To estimate (co)variance and heritabilities for the defined service-based heifer and cow fertility traits.
2. To determine genetic and phenotypic correlations between heifer and cow fertility traits.
3. To estimate breeding values, genetic and phenotypic trends for the fertility traits.

CHAPTER 2

LITERATURE REVIEW

2.1 ABSTRACT

The aim of this paper is to review the state of dairy cattle female fertility in South Africa and make comparisons to international efforts of improving fertility. Fertility in dairy cows is defined as the ability to conceive from first insemination soon after calving and to carry the calf full-term to calving. It is one of the main profit drivers in the dairy industry. It is a complex trait influenced by the environment, genetics and the interaction between these factors. Generally, there has been a decline in dairy cow fertility across breeds worldwide. This is due to intense selection for milk yield, milk components and body conformation traits. In addition, most fertility traits are negatively correlated to milk production traits. Milk production has been the focal point of selection programmes as it is directly linked to the profitability of the dairy enterprise. The low heritability of fertility traits is one of the factors that discouraged efforts to include fertility in genetic evaluations. However, due to its economic importance, female fertility was later included into the breeding objectives for dairy cattle in several countries. It is also important to note that even though most fertility traits are lowly heritable, there is some additive genetic variability that can be exploited.

2.2 INTRODUCTION

Fertility in a dairy cow was defined by Darwash *et al.* (1997), as the ability to conceive and maintain a pregnancy if served at the appropriate time in relation to ovulation. De Jong (1998) defined good cow fertility as an animal in lactation, which shows her heat early in the breeding season and getting pregnant from first insemination. Female fertility is a complex multi-factorial trait including the animals' genetic composition (Miglior, 1999), environmental conditions such as nutrition and climate (Muller *et al.*, 2014), the endocrine system (Potgieter, 2012), age of the animals and on-farm management practices. In enhancing fertility through advanced reproductive biotechnologies, a clear understanding of the hormonal mechanisms controlling estrus cycle is required for inseminators to detect estrus signs accurately thereby increasing pregnancy rates.

The breeding goal of most dairy farmers is to increase profitability of their enterprises. This should be achieved without any detriment to animal health and welfare and the environment. The milk yield of cows is directly linked to profitability of a dairy enterprise. However, there are several other profit drivers in addition to milk yield and composition, e.g. reproductive performance, disease resistance, feed efficiency and longevity. These functional traits increase the biological and economic efficiency of the farm, not by higher production outputs, but by decreasing the expense of production, highlighting the need for them to be incorporated into the national dairy cattle breeding programmes. The expense of production or input costs related to these functional traits

include repeated artificial insemination (AI) services, extra hormonal treatments, and veterinary examinations and treatments of cows that are susceptible to diseases and outsourcing replacement heifers. Major economic losses are also through culling as a result of reproductive problems and reduced incomes due to long calving intervals (Seegers, 2006). In a poor reproductive performance scenario, an average net economic loss of R4262.42 per cow per year was observed in the Netherlands (Inchaisri *et al.*, 2010).

Breeding programmes in the 1980s have primarily focused on selecting for increased milk production globally (Evans *et al.*, 1999; Pryce & Veerkamp, 2001). However, it is largely known that fertility in dairy cows strongly decreased over the last decades as milk production per cow significantly increased (Dillon *et al.*, 2006; Makgahlela *et al.*, 2007; Cassandro, 2014). This is due to the antagonistic relationship between fertility and milk production associated with pleiotropic effects of alleles for production and fertility (Glaze, 2011). Conventional breeding programs neglected fertility for several reasons including that it is not the produced commodity. Generally, fertility traits have low heritabilities (Table 1), indicating that they are heavily influenced by the environment. However, there is sufficient additive genetic variation to warrant genetic improvement through selection (Miglior *et al.*, 2005; Makgahlela *et al.*, 2007; Banga *et al.*, 2009; Muller *et al.*, 2014)

Table 2.1 Heritability (h^2) estimates and standard errors (SE) of fertility traits observed in different cattle breeds worldwide

Fertility trait	Breed	$h^2 \pm SE$	Country	Reference
Calving interval	Holstein-Friesian	0.07±0.00	Italy	Biffani <i>et al.</i> , 2003
	Holstein	0.03±0.01	South Africa	Makgahlela <i>et al.</i> , 2007
	Simmental	0.02±0.07	Turkey	Ulutas & Sezer, 2009
	Fogera Holstein-Friesian	0.05±0.09	Ethiopia	Zelege <i>et al.</i> , 2016
Age at first calving	Multiple breeds	0.13±0.01	New Zealand	Grosshans <i>et al.</i> , 1997
	Ayrshire	0.09±0.05	Kenya	Amimo <i>et al.</i> , 2006
	Holstein	0.24±0.02	South Africa	Makgahlela <i>et al.</i> , 2007
	Fogera Holstein-Friesian	0.15±0.23	Ethiopia	Zelege <i>et al.</i> , 2016
	Girolando	0.27±0.03	Brazil	Canaza-Cayo <i>et al.</i> , 2017
Days open	Multiple breeds	0.02±0.00	Brazil	Grosshans <i>et al.</i> , 1997
	Holstein	0.05±0.02	China	Guo <i>et al.</i> , 2014
	Holstein	0.03±0.00	Tunisia	Zaabza <i>et al.</i> , 2016
	Holstein	0.02±0.01	Iran	Rahbar <i>et al.</i> , 2016
	Fogera Holstein-Friesian	0.01±0.05	Ethiopia	Zelege <i>et al.</i> , 2016
Services per conception	Multiple breeds	0.01±0.01	New Zealand	Grosshans <i>et al.</i> , 1997
	Holstein	0.10±0.02	South Africa	Potgieter, 2012
	Holstein	0.01±0.01	Iran	Eghbalsaid, 2011
	Holstein	0.04±0.03	Iran	Rahbar <i>et al.</i> , 2016
	Holstein	0.03 ±0.00	Denmark	Zhe Zhang <i>et al.</i> , 2019
Calving to first service	Multiple breeds	0.03±0.00	Brazil	Grosshans <i>et al.</i> , 1997
	Holstein	0.14±0.02	Iran	Eghbalsaid, 2011
	Holstein	0.04±0.01	Czech Rep	Zink <i>et al.</i> , 2012
	Holstein	0.04±0.01	Iran	Toghiani, 2012
	Holstein-Friesian	0.07±0.00	Ireland	Berry <i>et al.</i> , 2013
	Holstein	0.06 ±0.00	Denmark	Zhang <i>et al.</i> , 2019
Non return rate 56d	Holstein-Friesian	0.02±0.00	Italy	Biffani <i>et al.</i> , 2003
	Holstein-Friesian	0.01±0.00	Netherlands	De Haer <i>et al.</i> , 2013
	Holstein	0.01±0.00	China	Liu <i>et al.</i> , 2017
	Holstein-Friesian	0.03±0.01	Germany	Yin & König, 2018
	Holstein	0.01 ±0.00	Denmark	Zhang <i>et al.</i> , 2019

The Nordic countries (i.e. Denmark, Sweden and Finland) were the first to include health and fertility traits into their selection programmes by the mid 1990's. Other countries such as New Zealand followed in 1998 and the USA in 2001 (Wesseldijk, 2004). Inclusion of fertility traits in South African selection programmes was only recommended in 2007 (Makgahlela *et al.*, 2007). To date, the genetic evaluation for fertility in South Africa is based on age at first calving (AFC) and calving interval (CI) (Makgahlela *et al.*, 2008; Mostert *et al.*, 2010; Ramatsoma *et al.*, 2014). The limitation of using traits that are derived from calving records is that these traits become available late in an animal's life and can easily be influenced by management or

breeder, the latter resulting in less accurate heritability estimates from bias in the measurements.

Inclusion of fertility in dairy cattle selection programs is based on its economic value to the herd. Advanced genomic technologies promise a leap forward in the genetic improvement of fertility, such as genomic selection, which exploit single nucleotide polymorphism (SNP) markers to predict breeding values for the breeding stock (Meuwissen *et al.*, 2001). Accuracy of genomic breeding value predictions in low heritable traits exceeds that of phenotypic values, which will accelerate the rate of genetic improvement for low heritable traits (Viana *et al.*, 2016). This paper reviews the state of female dairy cattle fertility in South Africa and comparisons are made to international efforts for genetic improvement of this complex trait.

2.3 EFFECT OF FERTILITY ON THE ECONOMICS OF DAIRY ENTERPRISES

Profitability of dairy cattle does not only depend on milk production but also on non-production characteristics such as fertility and health traits (Toghiani, 2012). These secondary traits minimize the cost of production and maximize the net return of the dairy enterprise (i.e., increase biological and economic efficiency). Sound reproductive management can have tremendous positive effects on profitability and one of the key components of modern dairy production is knowledge of the herd reproductive performance. Accurate and reliable on-farm records can help guide producers, veterinarians, and consultants to make better decisions regarding health and reproductive management (Overton, 2009). Poor reproductive performance is the primary reason for involuntary culling, accounting for 25% in France (Colleau & Moureaux, 1999), 21% in Iran (Ghaderi-Zefrehei *et al.*, 2017) and 53% in South Africa

(Anonymous, 2017). Involuntary culling also has a negative impact on dairy economics because buying a replacement heifer is far more expensive than the salvage value of a culled cow (Lavern, 2017). Economic losses can also be due to lost production due to prolonged CI (Van Arendonk *et al.*, 1989; Olori *et al.*, 2002). Banga *et al.*, (2009) showed that an increase in CI caused a profit decrease of ZAR 5.75 /cow/year in Holstein cattle agreeing with several international studies (Visscher *et al.*, 1994; DuPlessis & Roux, 1998; Holmes *et al.*, 2000; Olori *et al.*, 2002; Veerkamp *et al.*, 2002). This highlights the need to include all traits of economic importance in breeding objectives and selection indices, accurately weighted by their economic values. A study by Cervo *et al.* (2017) reported negative values for AFC from (-1 to -25) and CI (-0.4 to -24) indicating that producers need to select early calving animals and lower calving intervals in order to increase profit margins. Inclusion of these non-yield traits in selection indices is important for dairy producer's profits even though wide variation exists among countries in traits included in selection indexes and in relative economic weights (Shook, 2006).

2.4 BREEDING OBJECTIVES AND SELECTION INDICES INCLUDING FEMALE FERTILITY

Female fertility is largely influenced by the environment but genetics also play a significant role in the genetic improvement of dairy herds. High yielding cows have shown a decline in fertility requiring several AI services before conception and are more susceptible to diseases (Walsh *et al.*, 2011). This is due to the pleiotropic effect of genes for production and fertility, where similar genes underlie expression of these traits but in reverse modes (Glaze, 2011). Fertility traits are known to exhibit low

heritabilities (Table 1), which discouraged efforts to select for improved fertility. Thus, breeders thought that fertility could then be improved through better management systems. However, studies showed that there is sufficient additive genetic variation that exists amongst fertility traits to warrant improvement through selection (De Jong, 1998; Weigel & Rekaya, 2000; Norman *et al.*, 2009; De Haer *et al.*, 2013).

In the 1990's, Nordic countries (Denmark, Finland and Sweden) included fertility in their selection indices by using multi-trait selection (Leitch, 1994). The Nordic total merit –index (NTM) is currently used in breeding programmes to achieve overall animal genetic improvement. The NTM is described as a balanced breeding tool which focuses on the improvement of health and fertility traits, production and functional conformation, weighted as; health and fertility (53%), production (30%) and functional conformation (17%) (NTM Unlocked, 2017). Within the NTM, there are sub-indices for use in each country such as the S-index, Tjur index and Kokonaisjalostusarvo for Denmark, Sweden and Finland, respectively (Pedersen *et al.*, 2008). More weight is put on low heritable traits (health and fertility) to ensure a balanced breeding outcome. In Germany, the total merit index (TMI) is used for the Holstein cattle breed, which is weighted as follows; production (50%), longevity (25%), conformation (15%), udder health (5%) and reproduction (5%) (Rensing *et al.*, 2002). In the United States a total performance index (TPI) is used to aggregate traits divided into three main categories; production (43%), health (28%) and conformation (29%) (Meyer & Zwald, 2014). The South African index previously included production (63%) and type (37%) traits only (Wesseldijk, 2004). However, currently South African breeding objectives in dairy cattle comprises a small proportion of selection for milk production traits as a turnaround has been made in selection decisions for dairy cattle bulls by placing

emphasis on body conformation traits (e.g. udder, feet and legs, size, etc.), health traits (somatic cell counts indicator of mastitis), fertility (AFC and CI) and longevity (Theron & Mostert, 2019). The percentages or weights of the traits in the index changes as production and market prices changes and new estimated breeding values (EBV's) for the traits become available.

There are several possible measurements that can be used as selection criteria for female fertility. Interval traits are most commonly used for fertility evaluation, in part because of their simplicity and availability at a large scale (Potgieter, 2012). The only count trait used is number of services per conception (SPC) (Potgieter, 2012), which is also not largely explored due to its reliance on insemination and pregnancy records that are not routinely recorded in SA (Mostert *et al.*, 2010). Lack of sufficient data in SA makes it difficult to broadly evaluate fertility, hence genetic evaluations for fertility are based on AFC and CI obtained easily from calving records (Potgieter *et al.*, 2011). Although the genetic evaluations of CI ensure that fertility is included in breeding objectives, which is a good step towards the improvement of this trait, it has its limitations due to its unavailability until the second successful parturition. It results in biased management decisions and inaccurate prediction of breeding values as the evaluations are only based on cows that calve for the second time and more, excluding heifers and cows that are perceived to be least fertile and those culled for not getting pregnant (Esslemont, 1992; Haile-Mariam *et al.*, 2003; Muller *et al.*, 2012).

Potgieter *et al.*, (2011) and Muller *et al.*, (2012) explored the possibility of using on-farm AI service records for Holstein cattle, to derive additional measures of fertility. AI service data makes provision to identify traits such as Calving to First Service, number

of days open and SPC, which indicate the ability of the cows to conceive early in the breeding season from fewer services. Countries such as Ethiopia and the Netherlands have explored the use of reproductive performance records to estimate heritabilities and correlations for fertility traits (De Haer *et al.*, 2013; Zeleke *et al.*, 2016). The moderate to high positive genetic correlations observed in these studies suggest that improvement of one fertility trait is coupled with another. A single fertility trait would not serve well for selection purposes; thus a more comprehensive selection criteria for fertility needs to be combined in an index for optimum genetic progress of this complex trait. More research is required to increase the availability of such information and knowledge gaps, especially in South Africa.

2.5 RELATIONSHIPS BETWEEN FERTILITY AND PRODUCTION TRAITS

Production traits are easier to measure and directly proportional to herd profitability while measures of reproductive performance are difficult to define and record, which resulted in their exclusion in selection programmes (Evans *et al.*, 1999; Pryce & Veerkamp, 2001; Miglior *et al.*, 2005). Consequently, effective selection tools for genetic improvement of reproductive traits were limited (Gutiérrez *et al.*, 2002). Milk yield has since doubled in the past 40 years (Oltenacu & Broom, 2010). In the United States, the average milk production per cow over the period 1957-2007 increased by 5,997 kg, with 3,390 kg of this increase (56%) due to genetics (Van Raden, 2004). In SA, the Ayrshire breed has also made a remarkable genetic progress in production traits; milk production per lactation increased genetically with 44.3kg per year since 1983, butterfat production with 1.7kg/year and protein production with 1.4kg/year (Mostert *et al.*, 2013). Even though proper management, good nutrition and

environmental conditions also contributed to the increased milk yields, genetics played a huge role as animals went through intensive genetic selection through the use of artificial insemination (AI) and worldwide distribution of semen from elite progeny tested bulls (Oltenacu & Broom, 2010).

With increasing milk production, reproductive performance has been declining (Roxstroem *et al.*, 2001; Royal *et al.*, 2002a; Pryce *et al.*, 2004; Oltenacu & Broom, 2010). Several studies on the genetic relationships between fertility and production traits found that correlations between milk yield and fertility traits were antagonistic and statistically significant (Grosshans *et al.*, 1997; Roxstroem *et al.*, 2001; Strucken *et al.*, 2012; Tenghe *et al.*, 2015). High positive genetic correlations (Table 2) between 305d milk yield (MY) and CI, ranging from 47 to 69% with the highest unfavourable correlation observed in South African Holstein cattle. These indicate that an increase in milk yield consequently prolonged the ability to calve again thereby increasing the CI.

Table 2.2 Genetic correlations between 305d milk yield and calving interval in different dairy breeds

Breed	Genetic correlation	Country	References
CI			
Holstein Friesian	0.58	Australia	Haile-Mariam <i>et al.</i> , 2003
Holstein	0.69	South Africa	Makgahlela., <i>et al.</i> , 2007
Simmental	0.35	Turkey	Ulutas <i>et al.</i> , 2009
Holstein	0.59	Brazil	Toghiani, 2012
Brown Swiss	0.68	Turkey	Sahin <i>et al.</i> , 2014
Xinjiang Brown Cattle	0.47	China	Fu <i>et al.</i> , 2017
Girolando	0.59	Brazil	Canaza-Cayo <i>et al.</i> , 2017
SPC			
Holstein Friesian	0.40	UK	Kardamidden <i>et al.</i> , 2000
Holstein	0.98	Ireland	Evans <i>et al.</i> , 2002
Holstein Friesian	0.68	Netherland	Windig <i>et al.</i> , 2006
Sahiwal cattle	0.70	Kenya	Ilatsia <i>et al.</i> , 2007

In a sample of UK dairy cows monitored from 1975 to 1982 (n = 2503) and 1995 to 1998 (n = 704), calving rates to first service declined from 55.6% to 39.7% (Royal *et al.*, 2000a). There is also evidence of unfavorable relationship between milk production and estrus behavior with shorter estrus periods (5.5 vs 11.1 h) in high (> 40 kg per day) relative to low (< 30 kg per day) producing cows (Lopez *et al.*, 2004). A study conducted in Poland showed that increased milk yield of first calvers (from ≤5 000 kg to >8 000 kg) had a negative effect on their fertility in the first reproductive cycle, calving interval increased from 378 to 517 days, service period lengthened from 24 to 130 days and insemination interval increased from 1.63 to 3.44 (Sawa & Bogucki, 2011). In South Africa, Makgahlela (2008) reported that CI of Holstein cows increased from 386 in 1984 to 420 days in 2004. Increasing the interval between two calving dates reduces the number of calves born per herd/year. Reklewski *et al.* (2003) pointed out that the negative effect of high milk production on fertility may be due to the fact that daily lactation yield peaks during the period when cows are more likely to conceive, i.e. between 60 and 90 days after calving. The primary reason for reproductive disturbances is the aggravation of the negative energy balance, which

leads to intense mobilization of body fat reserves, thus increasing the incidence of metabolic and hormonal disorders and lengthening the period between calving and first estrus after calving (Reklewski *et al.*, 2003).

2.6 FEMALE FERTILITY IN DAIRY CATTLE AS AFFECTED BY MANAGEMENT PRACTICES

Success or failure of dairy farming to a greater extent depends on the farmer's or breeder's management skills together with market factors, environmental factors and the herd genetic composition. Good decision making is required from the farmer, coupled with an in depth general knowledge of dairy herd management because the farmer will decide on which bulls and cows to breed and how long the cows can be kept in milk.

Overall dairy herd health and nutrition are primary determinants of fertility (whether heifers and cows will conceive). Feeding level of young animals will affect the age at which they reach puberty while in mature animals' inadequate nutrition reduces the production of ova, which can result in failure to conceive (Shortle, 2014). Nutritional imbalances are one cause of poor fertility in dairy cattle because an improper diet plan could result in a negative energy balance. Negative energy balance normally occurs during early lactation because feed intake is low while milk production is greater as the cows are transitioning, these causes the animal to use body reserves to overcome the energy deficit (Ibtisham *et al.*, 2018). Formulating diets to meet requirements of the cows while avoiding over-consumption of energy, may improve outcomes of the transition period and lead to improved fertility (Cardoso, 2017).

Body condition scoring (BCS) is one of the good herd management tools to check the body reserves and energy status of the cattle. Good health, milk production, fertility and fitness depend on a good BCS, it is recommended that BCS should not fall below 2 to 2.5 and should be the same at drying off and calving (Garnsworthy, 2007). The BCS has a direct effect on fertility of dairy cattle. Carvalho *et al.* (2014) showed that cows that maintained BCS from calving to 21 days after calving had higher pregnancy per AI at 40 days (83.5%) than cows that lost BCS (25.1%) during that same period. Klopčič *et al.* (2011) noted that animals that stay in good condition in early lactation show shorter CI. Kadarmideen (2004) showed that BCS has favourable genetic correlations with fertility traits (-0.35 with DFS and 0.04 with NRR) and also that improvement on BCS is coupled with a correlated increase in the genetic merit for lactation somatic cell score (SCS.) Through selection of BCS and SCS an opportunity for indirect selection of resistance to mastitis is provided because SCS in milk has genetic correlation of about 70% with clinical mastitis (Kadarmideen & Pryce, 2001). The BCS is detrimental to post-partum health as showed by Markusfeld *et al.*, (1997) where under-conditioned cows at drying off were at greater risk of having retained placenta, whereas cows that lost more body condition during the dry period suffered more from both retained placenta and metritis. A well balanced ration is recommended throughout all the stages of a producing dairy cow to avoid the negative effects caused by poor nutrition.

There are several other fertility factors that cannot be resolved through proper management such as the reproductive system of the cow (e.g. uterine infections and embryonic deaths). However, certain fertility factors (e.g. nutrition, veterinary services,

estrus timing and milking duration) can be controlled through proper management which may have an intermediate influence on factors controlled by the reproductive system of the cow (Senger, 2001).

2.7 ROLE OF PHYSIOLOGICAL MECHANISMS ON FERTILITY

Successful reproduction is the result of a chain of events including resumption of estrous cycles postpartum, development and ovulation of a healthy oocyte, fertilization, embryo development, implantation in the uterus, maintenance of pregnancy and parturition (Garnsworthy *et al.*, 2008). Proficiency of an inseminator is tested by adequate detection of estrus because failure to conceive will lead to a repeated cycle of estrus and consequently longer CI.

Good heat detection is the key for a successful breeding program. Standing to be mounted is considered the main behavioral sign identifying an estrous period and is used to determine the correct time to inseminate; however, this traditional way of detecting cows is unsatisfactory (Van Eerdenburg *et al.*, 1996). Moreover, in high-yielding herds, the percentage of cows that display standing to be mounted by other cows has decreased. A study by Roelofs *et al.* (2005b) showed that only 58% of cows were observed in standing estrus, leaving it more difficult to detect estrus. As a result, submission rate to AI will decrease and therefore leading to reduced reproductive efficiency (Crowe *et al.*, 2018). However, the use of a combination of signs of estrus and heat detection aids has a positive association with reproductive efficiency (Cowen *et al.*, 1998; Rao *et al.*, 2013). Other methods for detection and quantifying of estrus,

such as pedometers (Roelofs *et al.*, 2005a) and electronic activity tags have proven very effective in improving estrus detection (Lovendahl & Chagunda, 2010).

A healthy dairy cow should ovulate the first dominant follicle at around 15 days postpartum although it may not show behavioral signs during first ovulation. This 'silent estrus' is thought to be a result of high estradiol (E2) concentrations from fetal origin at the end of gestation, which induces 'refractoriness' in the hypothalamus to E2 at the first postpartum ovulation (Boer *et al.*, 2010). However, behavioral signs will be present at the subsequent estrus due to the effect of the corpus luteum produced after the first ovulation which provides the progesterone (P₄) that removes the refractory state.

The percentage of cows becoming pregnant from first postpartum insemination has declined from 55.6% to 39.7% between 1975-1982 and 1995-1998, which was attributed to an increase in the proportion of cows exhibiting atypical ovarian hormone patterns from 32% to 44% (Royal *et al.*, 2000a). Atypical ovarian hormone patterns, such as extended anestrus or prolonged high progesterone concentrations often require pharmacological interventions before normal cycles can be resumed (Pring *et al.*, 2012). The delay of normal patterns of early resumption of ovulation in high yielding Holstein cows may be due to the effects of severe negative energy balance, dystocia, retained placental membranes and uterine infections (Crowe *et al.*, 2014). The key to optimizing resumption of ovulation in dairy cows is appropriate pre-calving nutrition and management so that the cows calve down in optimal body condition (2.75 to 3.0) with postpartum body condition loss restricted to <0.5 (Crowe *et al.*, 2014). This will ensure that cows are inseminated shortly after calving and conceive earlier resulting in shorter calving intervals.

2.8 INTEGRATION OF GENOMIC TECHNOLOGIES TO ACCELERATE GENETIC IMPROVEMENT FOR FERTILITY

Advancements in genotyping by sequencing technologies have facilitated the identification of SNPs, which provides additional data for use in genetic evaluations of animals. Genomic selection (GS) identifies genetically superior animals based on breeding values predicted as the sum of allele substitution effects of thousands of SNP markers from the reference populations with both phenotypes and genotypes (Meuwissen *et al.*, 2001). This allows selection in young animals without phenotypic information, reduces generation interval thereby accelerating the rate of genetic improvement (Schaeffer, 2006; Goddard, 2009). High genetic gains can be achieved when using young bulls without progeny performances as sires or bulls and sires or cows at the tender age of 2 years (De Roos *et al.*, 2011; Buch *et al.*, 2012) with selection accuracies >70% for production traits (Hayes *et al.*, 2009), which were historically achievable after 7 years using traditional methods). Several methods have been developed for genomic evaluations, including the multiple steps where SNP effects are estimated and summed to obtain direct genomic values or are used to build a genomic relationship matrix that simply replaces the pedigree-derived numerator relationship matrix (Habier *et al.*, 2007, Van Raden, 2008). The genomic data would be subsequently blended with EBV to obtain genomic breeding values (GEBV). In what has been termed the single-step or unified approach, the pedigree and genomic information are combined into a single relationship matrix, which then enters the mixed-model equations to obtain GEBV for both genotyped and ungenotyped animals (Miszta *et al.*, 2009; Christensen & Lund, 2010). Genomic selection will be especially

important in accelerating genetic improvement for low heritable complex traits such as indicators of health and fertility.

Genomic evaluations are implemented in commercial dairy herds of most countries such as the United States, Netherlands, France and the Nordic countries. In South Africa, the dairy genomics programme (DGP) was established in 2016 with the aim of assembling the infrastructure for delivering genomic selection technology in SA dairy farmers (Mostert & Makgahlela, 2017; Van Marle-Köster & Visser, 2018). Reliability of genomic predictions were found to be considerably greater than those of the conventional parent averages (PA), averaged over 18 traits, reliability of GEBV was between 42 and 55% while reliability of PA was 29% reliability of PA (Su *et al.*, 2010).

The cost of genotyping is a limiting factor towards the adoption of genomic selection in developing countries such as South Africa. However, the expenses of genotyping can be countered by greater saving costs due to the elimination of progeny testing and additional annual monetary genetic gain due to the reduction of generation intervals in genomic breeding programmes (GBP). König *et al.* (2009) showed this in the study where a distinct economic advantage in discounted profit was found for all scenarios of GBP in the range of factor 1.36 to 2.59. Kariuki *et al.* (2017) also supported the cost effectiveness of genomic selection as compared to progeny testing in their gross margins study for progeny testing (PT) and GS schemes. This highlights that GS breeding scheme is economically viable for developing countries because the higher the margin, the more effective the company's management is in generating revenue for each euro of cost. Imputation algorithms can be applied to derive high-density genotypes from low-density genotypes and the loss in accuracy of GEBV estimated

from imputed genotypes is reported to be between 0 and 45% (Habier *et al.*, 2009; Weigel *et al.*, 2010; Lashmar *et al.*, 2019). Imputation can be used to deduce missing genotypes and could be helpful in increasing the requisite large reference populations needed for accurate genomic selection (Weng *et al.*, 2012). The shift towards genomic selection will assist in improving low heritable traits such as fertility but the need to have appropriate measures for female fertility remains the cornerstone for the much-articulated gains in genomic selection.

2.9 CONCLUSION

The declining trend in fertility has been successfully reversed by its inclusion in multitrait selection indexes with production and other economically important traits worldwide. The current fertility state of the South African dairy industry is not desirable as it is evident through the increasing CI. However, SA is following the world trends of including health and functional traits in their selection indices, which is a crucial step towards improving fertility performance. More research is required on female fertility of South African dairy cattle, to explore traits such as SPC for use in addition to CI and AFC to allow early selection decisions and minimise bias, in order to accelerate the South African dairy industry. Successful implementation of additional fertility traits into genetic improvement programs of South African dairy cattle depends on whole-herd reporting and cattle breeders optimizing the use of available technologies to improve the current state of female fertility. Genomic selection is a promising opportunity for accelerating genetic improvement of complex traits such as fertility that have been challenging to improve using solely traditional methods.

CHAPTER 3

Non-genetic factors affecting female fertility traits

3.1 ABSTRACT

The aim of this study was to investigate non-genetic factors affecting heifer and cow fertility traits of South African Holstein cattle. A total of 64464 artificial insemination (AI) service records of cows born during the period 1981-2013 were used to define fertility traits. Traits for heifers were age at first service (AFS), age at first calving (AFC) and number of services per conception (SPCh). Traits for cows were the interval from calving to first service (CFS), number of days open (DO), number of services per conception (SPC) and binary traits for first service within 80 days post-partum (FS80d), whether cows were confirmed pregnant within 100 days post-partum (PD100d) or 200 days post-partum (PD200d). Statistical testing for model effects was performed using lme4 package in R for linear mixed models. Non-genetic effects tested were herd-year-season of birth or calving contemporary groups, age at insemination or calving age and lactation number which generally had a significant effect ($P < 0.05$) on the fertility traits. It is evident that the effects tested should mostly be included in analyses aimed at estimating genetic parameters for these fertility traits to ensure unbiased parameters as they have a significant effect on the traits. The average AFS was 16.8 ± 3.5 months while AFC was 26.7 ± 3.9 months, which appears to be similar to international standards. The SPCh in heifers was lower (1.54 ± 1.0) than in cows (2.18 ± 1.37), indicating that younger heifers require fewer inseminations on average for conception than the older cows.

3.2 INTRODUCTION

The genetic evaluation of fertility is difficult as fertility is a complex trait, which is difficult to define and record. Fertility traits were not widely used in dairy cattle selection programs mainly because they are known to exhibit low heritability (Pryce *et al.*, 1998; Kardamideen, 2004). However, several studies showed that fertility traits have high additive genetic variation, which warrants selection for these traits (Raheja *et al.*, 1989; Oltenacu, 1991; Grosshans *et al.*, 1997; De Jong, 1998). This resulted in the inclusion of fertility traits in selection programmes as early as the 1990s in the Nordic countries. In SA for dairy cows, only AFC and CI are included in routine evaluations for fertility (Makgahlela *et al.*, 2008). Artificial insemination records provide an opportunity to include more fertility traits for dairy cows. However, such data in SA are not recorded routinely into the national database but are kept on farm for management purposes. Interval traits include the interval from calving date to first service date and first service date to conception date, count traits include number of services per conception while success traits include whether cows were confirmed pregnant within 100 or 200 days post-partum. These traits were shown by several studies to be important indicators of reproductive performance in dairy cattle (Averill *et al.*, 2004; Jamrozik *et al.*, 2005; Biffani *et al.*, 2005).

A number of non-genetic factors such as lactation number, calving year, calving season, herd management practices and nutrition affect the fertility of dairy cows (Muller *et al.*, 2014). Therefore, improvement of reproductive performance of dairy animals could be achieved through improved genetics (i.e., superior breeding stock) and environmental conditions (Katkasame *et al.*, 1996) by managing the two

simultaneously. Evaluation of genetic and non-genetic factors provide information for establishing sound breeding programs, which helps in selecting animals with superior genetic merits. The aim of this study was to identify non-genetic factors affecting female fertility traits in South African Holstein cattle population with the aim of including in the estimation of genetic parameters and breeding values.

3.3 MATERIALS AND METHODS

3.3.1 Data

The AI service records (n = 64 644) of cows born between 1981 and 2013 from 18 South African Holstein dairy herds were analysed. The outcome of each AI event was known. A veterinarian based pregnancy diagnosis on rectal palpation, usually during monthly farm visits. Data received included birth dates, service and calving dates of each animal, lactation number, dam and sire identification numbers from which heifer and cow fertility traits were calculated. The derived traits measured the ability of heifers to reach puberty early, ability of cows to show heat early in the breeding period and the probability of the success of insemination and confirmation of pregnancy. Non-interval traits were recorded as binary traits coded as 1 = no and 2 = yes.

Table 3.1 Description of the fertility traits defined from the data set.

Trait	Trait category	Description of the trait
Age at first service (AFS)	Interval	Age at which a heifer was first inseminated (expressed in months)
Age at first calving (AFC)	Interval	Age at which a heifer gives birth to its first calf (expressed in months)
Services per conception (SPCh)	Count	Number of services required for a heifer to conceive
Calving to first service (CFS)	Interval	Number of days from calving date to the date of the next first service
Days Open (DO)	Interval	Number of days from calving date to conception date
Services per conception (SPC)	Count	Number of services required for a cow to conceive
First service < 80days (FS80d)	Success	Success trait – whether the cow was inseminated within 80 days post-partum
Pregnant < 100days (PD100d)	Success	Success trait – whether the cow was confirmed pregnant within 100days post-partum
Pregnant < 200 days (PD200d)	Success	Success trait – whether the cow was confirmed pregnant within 200days postpartum

3.3.2 Editing

Data editing was carried out using the R-CRAN program (R Core Team, 2017). Two subsets of data were extracted from the original dataset based on heifer (to 1st parity) and cow traits (2nd parity and above). The datasets were edited to remove outliers for each trait. For example, observations greater than three standard deviations from the mean for each trait were excluded. Removing outliers from the dataset included deleting records below 21 days and above 250 days for CFS, and while for DO records below 21 days and above 435 days were deleted, as records outside this range are likely to be physiologically abnormal or wrongly recorded. Two calving seasons were defined as summer (October to March) and winter (April to September) (Dube, 2006). Herd-year-season of birth or calving was defined as a contemporary group. Animals with unknown birth dates were removed from the data set. This editing resulted into two datasets of 10017 and 24909 AI records for heifers and cows, respectively.

3.3.3 Statistical analysis

The lme4 package (Bates *et al.*, 2015) implemented in R-CRAN was used to test non-genetic factors associated with the fertility traits. The analysis of variance (ANOVA) function in R was used to test significant effects affecting the traits. Tested non-genetic effects significantly ($P < 0.05$) affecting fertility traits were included in the estimation of genetic parameters and breeding values.

The following model was used:

$$Y_{ijkl} = HYS_i + \beta AGE_j + L_k + e_{ijkl} \quad [1]$$

Where Y_{ijkl} is the observation for the trait, HYS_i is the fixed effect of herd-year-season of birth for heifer traits or herd year season of calving for cow traits, AGE_j is the effect of age at insemination for heifers fitted for SPCh or age at calving for cow traits, L_k is the fixed effect for the k^{th} lactation for cow traits and e_{ijkl} is the random residual term.

3.4 RESULTS AND DISCUSSION

Descriptive statistics of the data are presented in Table 3.2. The average AFS was 17 months while AFC was 27 months. The SPCh in heifers was lower (1.54) than in cows (2.18), indicating that younger heifers require fewer inseminations on average for conception than the older cows. This is somewhat expected as heifers have not yet started lactating to effect genes underlying production i.e., the pleiotropic effect of

genes is not initiated. On average, it took 90 days for the cows to be ready for first service after calving, which was higher than 81 and 84 days reported by Gonza'lez-recio & Alenda (2005) and Kadarmideen *et al.* (2000) respectively. Although CFS was, lower than the 92 days average reported by Tenghe *et al.* (2015). High CFS interval leads to greater DO, which averaged at 137 days in this study. This subsequently extends CI beyond the recommended 365 days, even with a good heat detection and high pregnancy rates.

Table 3.2 Number of service records (n), mean, standard deviation (SD), minimum (Min) and maximum (Max) for heifer and cow fertility traits

Groups	Variable	Mean	SD	Min	Max
Heifers (n=10017)	AFS (months)	16.8	3.5	10	30
	AFC (months)	26.7	3.9	20	48
	SPCh	1.54	0.98	1	8
Cows (n=24909)	SPC	2.18	1.57	1	8
	CFS (days)	90	37	21	250
	DO (days)	137	72	21	435
	FS80d	1.45	0.50	1	2
	PD100d	1.38	0.48	1	2
	PD200d	1.82	0.38	1	2

Age at first service (AFS); age at first calving (AFC); number of services per conception for heifers (SPCh); number of services per conception for cows (SPC); number of days from calving to first service (CFS); number of days open (DO); whether cows were inseminated for the first time within 80 days post-partum (FS80d); whether cows were confirmed pregnant within 100 days post-partum (PD100d) and whether cows were confirmed pregnant within 200 days post-partum (PD200d).

The non-genetic factors fitted in the statistical models for estimation of genetic parameters are shown on the below table with crosses (x) denoting significant effects.

Table 3.3 Significant and non-significant factors affecting heifer and cow fertility traits of South African Holstein cattle

Traits	HYS	Parity	Insemination or calving age
AFS	x	-	-
AFC	x	-	-
SPCh	x	-	x
CFS	x	X	x
DO	x	X	x
SPC	x	X	x
FS80d	x	X	x
PD100d	x	X	x
PD200d	x	X	x

The ANOVA results are illustrated for non-genetic factors affecting heifer fertility (Table 3.4), cow fertility (Table 3.5) and cow binary traits (Table 3.6).

Table 3.4 Estimated mean squares of non-genetic factors affecting heifer fertility traits in South African Holstein Cattle Population

Source of variance	df	AFS		AFC		SPCh	
		Mean squares	P-value	Mean square	P-value	Mean squares	P-value
Herd	13	18601.9	0.01	20745.0	<0.01	1.93	0.16
Year	31	5405.4	<0.01	6967.0	<0.01	0.002	0.33
Season	2	292.0	<0.01	594.2	<0.01	11.0	0.07
Age at insemination	199	-	-	-	-	50.3	<0.01*
H*Y*S	247	79.6	0.003	147.1	0.004	2.54	0.10

Age at first service (AFS), age at first calving (AFC), heifer services per conception (SPCh), the interaction between herd year and season of birth (H*Y*S)

The herd effect was highly significant ($P < 0.05$) for AFS and AFC, however not significant for SPCh (Table 3.4). This indicates that the breeder can decide when to start breeding the heifers or it can be delayed, and different management strategies

affect heifer age at first service and calving. Jamrozik *et al.* (2005) indicated that female fertility would be lower in herds with poor management. The interaction between herd, year and season was not significant for services per conception, although significant for AFS and AFC. It was however included in the final model for SPC, as the overall model was significant which might be because season was highly significant for SPC. Age at insemination was highly significant ($P<0.01$) for number of services required for conception which may support the perception that older animals requires more services to conceive while younger animals requires less services to conceive.

Table 3.5 shows that herd effect significantly ($P<0.01$) affected CFS and DO, indicating that the breeder can decide to keep cows or have shorter intervals by inseminating cows earlier after calving. Studies have reported similar results where herd affected fertility traits significantly (Amimo *et al.*, 2006; M'Hamdi *et al.*, 2011). The interaction between herd, year and season of calving also had a significant effect ($P<0.01$) on CFS and DO.

Table 3.5 Estimated mean squares of non-genetic factors affecting cow fertility traits in South African Holstein Cattle Population

Source	Df	CFS		DO		SPC	
		Mean squares	P-value	Mean squares	P-value	Mean squares	P-value
Herd	17	24102	<0.01	1004	<0.01	34.85	0.01
year	16	31761	<0.01	657627	<0.01	235.97	<0.01
Season	2	2311	0.006	101479	<0.01	46.58	<0.01
Parity	13	19287	<0.01	5	<0.01	23.75	0.002
Calving age	148	183301	<0.01	332352	<0.01	8.65	0.05
H*Y*S	346	13998	0.001	68683	0.002	4.65	0.16

Calving to first service (CFS), number of days open (DO), cow services per conception (SPC), interaction between herd year and season of birth (H*Y*S)

The variation of CFS from one herd to another could be attributed to differences in heat detection and semen insemination skills and techniques, and overall farm management style. In addition, inadequate nutrition between herds could lead to low BCS, delaying the cow's ability to recuperate after calving. Year of calving was also a source of variation for all the cow traits as reported in previous studies (Muasya, 2005; Amimo *et al.*, 2006). Effects of herd, calving year and calving season were found to be statistically significant ($P<0.01$) for SPC. However, the interaction between herd, year and season of calving was not significant ($P=0.16$) for SPC. Its inclusion in the overall model was however, highly significant ($P<0.01$). The variation of SPC in different herds could be attributable to inseminator proficiency.

Age at calving was highly significant ($P<0.01$) for both CFS and DO, however it was not significant for SPC ($P=0.05$). Parity effect was significant for CFS, DO and SPC. An increase of interval between calving and first insemination was observed with the increasing lactation number (Cilek & Tekin, 2007). Cow fertility is known to deteriorate with lactation number (Weller & Ron, 1992). Balendran *et al.* (2008) in a study comparing pregnancy rate between heifers and first, second, third and fourth parity cows, observed markedly low pregnancy rate with high parity cows, indicating that conception was deteriorating with increasing parity.

Table 3.6 Estimated mean squares of non-genetic factors affecting binary cow traits in South African Holstein Cattle Population

Source	Df	CFS80d		PD100d		PD200d	
		Mean square	P-value	Mean square	P-value	Mean square	P-value
Herd	17	24.98	<0.01	0.78	<0.01	0.98	0.009
year	16	4.73	<0.01	39.79	<0.01	5.94	<0.01
Season	2	0.56	0.005	4.75	<0.01	2.70	<0.01
Parity	13	0.26	<0.01	0.17	<0.01	0.14	<0.01
Calving age	148	19.92	<0.01	8.54	<0.01	6.01	<0.01
H*Y*S	346	1.17	0.02	3.45	0.001	1.05	0.007

Calving to first service within 80days post-partum (CFS80d), cows confirmed pregnant within 100 days post-partum (PD100d), cows confirmed pregnant within 200 days post-partum (PD200d), the interaction between herd, year and season of calving (H*Y*S)

Herd had a significant effect ($P<0.01$) on all the binary traits (CFS80d, PD100d and PD200d) showing that breeders choose which cows to inseminate early after calving or keep longer in milk (Table 3.6). Year and season of calving had a significant effect ($P<0.01$). Farmers mostly decide on early inseminations during winter months because of the general perception that fertility is low during the hot summer months. López-Gatius (2002) reported decrease in cyclicity and SPC during warmer summer months compared to cooler winter months.

Age at calving and lactation number also had a significant difference ($P<0.01$) on all the binary traits indicating that some cows recover quicker post-partum and return to service earlier than others. The interaction of herd, year and season of calving had a significant effect ($P<0.05$) on all the binary traits and the overall model used was also significant ($P<0.01$).

3.5 CONCLUSION

The tested non-genetic factors including herd, year, season, lactation number and calving age significantly affected most fertility traits. The exception was the interaction between herd, year and season of birth or calving, which were not significant as a model term but explained more variation in an all-factor model. All significant non-genetic factors will be included in the linear mixed models for the estimation of genetic parameters and the genetic evaluation of estimated breeding values.

CHAPTER 4

Estimation of genetic parameters, phenotypic and genetic correlations among service based heifer and cow fertility traits of Holstein cattle

4.1 ABSTRACT

Data including 64 464 AI service records of cows born between 1981 and 2013, and 18592 pedigree records covering the period 1981 and 2013 were used in the estimation of genetic parameters (i.e., (co) variance and heritabilities for AI-based fertility traits. The observed heritability estimates ranged from low (0.02) for interval and success traits to moderate (0.24) for binary traits. The heritability for PD200d was the highest (0.24) while AFS and SPC had the lowest (0.02). These heritabilities indicate potential genetic improvement for the studied fertility traits through selection. The genetic correlations among fertility traits were positive ranging from 0.05 between services per conception in heifers and services per conception in cows to 0.95 between age at first calving and services per conception in cows, thus a directly and positively proportional association between traits. Phenotypic correlations among heifer and cow traits were low and negative ranging between -0.03 and -0.15, indicating that there is no phenotypic relationship amongst heifer and cow fertility traits. The observed high positive genetic relationships amongst the fertility traits indicate that an improvement in one trait results in a corresponding improvement in another trait. These can enhance selection response, as the direction of the correlation will be in accord to the direction of selection.

4.2 INTRODUCTION

The goal of dairy cattle farming is to increase milk production at the lowest possible input costs. Input factors such as fertility have to be considered in selection programmes to achieve optimal benefit and profitability of the dairy enterprise. A cow that conceive and calves every year from the start of her productive life will have a greater amount of milk produced in her lifetime. Poor reproductive performance consequently leads to high input costs due to repeated inseminations, extra hormonal treatments for those cows failing to conceive, extended lactations leading to increased days open and high inter-calving periods. However, due to milk being the produced commodity, more emphasis was on selection for high milk production whereas there was little emphasis on fertility traits in dairy cattle selection schemes.

Heritabilities for fertility traits are relatively low, indicating strong influence by environmental factors, which largely discouraged efforts for their genetic improvement through selection (Miglior *et al.*, 2005; Weigel & Rekaya, 2000). The economic impact of reproduction on a dairy enterprise, cannot be ignored, over the last decade many countries included fertility in their genetic evaluations (Miglior *et al.*, 2005). A single trait cannot cover all aspects of fertility. Hence, several types of fertility traits are used in genetic evaluations such as binary and interval traits. Success or failure of an insemination event is usually measured as a binary trait for the cow that is being inseminated. Interval traits such as calving interval, number of days open and number of days to first insemination are most commonly used for fertility evaluation. It is a challenge to decide which fertility traits to include in genetic evaluations due to lack of consistent data recording and the complex nature of fertility making it difficult to record

and measure. The pleiotropic effect of common alleles for fertility and production traits but in reverse modes resulted in, the long-term deterioration in reproductive performance of high-yielding dairy cows (Zink *et al.* 2012; Yamazaki *et al.* 2014).

In South Africa, only AFC and CI are used in the genetic improvement of fertility. These traits serve as good step towards improvement of fertility, more exposed to management bias and CI is available late in an animal's life. Traits such as age at first service, non-return rate, services per conception and age at first calving could be used to evaluate heifers from early stages while cows could be evaluated using traits such as number of days open and the interval from calving to first service. The information to derive such traits is obtained from service records. Although in South Africa, recording of service data and calving information has not yet been implemented on the national scale; farmers for management purposes keep such records. Therefore, the current study used information obtained from on-farm milk recording systems to derive additional fertility traits and estimate genetic parameters, phenotypic and genetic correlations of female fertility traits in South African Holsteins.

4.3 MATERIALS AND METHODS

4.3.1 Data

The dataset used for analysis can be referred to in Chapter 3 and the traits were described in Table 3.1.

4.3.2 Statistical analysis

Descriptive statistics (Table 3.2) were computed using R-CRAN functions and histograms were plotted using the Hist function also in R-CRAN (R Core Team, 2017). Significant non-genetic factors were fitted in the statistical models for estimation of variance components. The variance component estimations were first launched using AI REML of BLUPF90 family of programs (Misztal et al., 2016) which maximizes the likelihood, yielding variance estimates corresponding to the maximum of that likelihood (Misztal, 2008). Multiple sets of bivariate analysis in AI REML yielded realistic results while multivariate analysis gave an error owing to over parameterization of the model. The AI REML software does not allow simultaneous analysis of categorical and continuous traits. Hence, the reported results were obtained from a multivariate analysis using THRGIBBS1F90 and POSTGIBBSF90 of BLUPF90 family of programs (Misztal *et al.*, 2018). Two sets of analysis were carried out in this study: 1) heritabilities of cow fertility traits (DO, SPC and CFS) and binary traits (FS80d, PD100d and PD200d), as well as their genetic correlations, and 2) estimation of heritabilities for heifer traits (AFS, AFC and SPCh) and genetic correlations between heifer and cow fertility traits. The THRGIBBS1F90 uses Bayesian inference to estimate the unnormalized joint posterior distribution, where inferences are made on the marginal posterior distributions, in a Bayesian framework; the presence of nuisance parameters

does not pose any formal, theoretical problems (STATISTIC LLC). Bayesian method implements a Markov chain Monte Carlo (MCMC) method and Gibbs sampling to estimate the marginal posterior densities of the different parameters (Van der merve & Pretorious, 2003). The software allows simultaneous analysis of categorical and continuous traits, which were used in this study. The following animal models were fitted for heifer (SPCh, AFS and AFC) and cow (SPC, CFS, DO, CFS80d, PD100d and PD200d) traits:

$$y = Xb + Za + e \quad [2]$$

$$y = Xb + Za + Wpe + e \quad [3]$$

Where: y was the vector of observations; b was the vector of fixed effects which consists of herd-year-season of birth (for heifer traits), herd-year-season of calving (for cow traits), parity fitted only (for cow traits), age at insemination fitted only for (SPCh) and age at calving fitted (for cow traits); a was the vector of additive genetic effects; pe was the vector of random permanent environmental effects (fitted only for cow traits); e was the vector of residual effects; X , Z , and W were the corresponding incidence matrices. It was assumed that the expectation E of the variables are:

$E(y) = Xb$; $E(a) = E(e) = 0$ and the $\text{var}(a) = A\sigma_a^2 = G$, $\text{var}(pe) = I\sigma_{pe}^2$ and $\text{var}(e) = I\sigma_e^2 = R$; therefore, $\text{var}(y) = ZAZ'\sigma_a^2 + WI\sigma_{pe}^2W' + R$, where A is the numerator relationship matrix.

The three-trait animal model was fitted as follows:

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} X_1 & 0 & 0 \\ 0 & X_2 & 0 \\ 0 & 0 & X_3 \end{bmatrix} \begin{bmatrix} \beta_1 \\ \beta_2 \\ \beta_3 \end{bmatrix} + \begin{bmatrix} Z_1 & 0 & 0 \\ 0 & Z_2 & 0 \\ 0 & 0 & Z_3 \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix} + \begin{bmatrix} W_1 & 0 & 0 \\ 0 & W_2 & 0 \\ 0 & 0 & W_3 \end{bmatrix} \begin{bmatrix} pe_1 \\ pe_2 \\ pe_3 \end{bmatrix} + \begin{bmatrix} e_1 \\ e_2 \\ e_3 \end{bmatrix} \quad [4]$$

Where: y_i was the vector of observations; $i = 1, 2$ and 3 representing fertility traits; β_i was the vector of fixed effects for the i th trait which consists of herd-year-season of birth (for heifer traits), herd-year-season of calving (for cow traits), parity fitted (for cow traits), age at insemination fitted for (SPCh) and age at calving fitted (for cow traits); a_i was the vector of additive genetic effects for the i th trait; pe_i was the vector of random permanent environmental effects (fitted only for cow traits); e_i was the vector of residual effects for the i th trait; X, Z , and W were the corresponding incidence matrices.

Single chains of 200 000 cycles were launched in the THRGIBBS1F90 with the first 50 000 cycles used as the burn-in period during which the sampling process moves from the initial values of the parameters to those from the joint posterior distribution. This was followed by POSTGIBBS analysis to verify the burn-in period, determine the convergence by visual examination of plots of covariance components within each iteration and finally use posterior means to calculate heritabilities and genetic

correlations. The variance components estimates from the single trait analysis were no different from the multi-trait analysis.

4.4 RESULTS AND DISCUSSION

4.4.1 Estimates of variance components and heritabilities for heifer and cow fertility traits

The variance components and heritability estimates are shown in Table 4.1. Heritability estimates for all traits ranged from 0.02 ± 0.00 to 0.08 ± 0.01 in heifers and 0.04 ± 0.00 to 0.24 ± 0.00 in cows. As expected, heritability estimates were generally low, except for the binary trait PD200d (0.24 ± 0.00).

Table 4.1 The additive genetic and residual variances, heritabilities and standard errors (Heritability \pm SE) for fertility traits using a three-trait animal model.

Traits	Additive genetic	Residual Variances	Heritability \pm SE
AFS	0.003	0.166	0.02 ± 0.04
AFC	0.863	10.39	0.08 ± 0.01
SPCh	0.002	0.128	0.02 ± 0.00
SPC	0.051	1.144	0.04 ± 0.00
CFS	75.17	1077	0.06 ± 0.00
DO	228.6	3996	0.05 ± 0.01
FS80d	0.077	1.057	0.07 ± 0.02
PD100d	0.161	1.015	0.13 ± 0.00
PD200d	0.339	1.014	0.24 ± 0.00

age at first service (AFS); age at first calving (AFC); heifer number of services per conception (SPCh); cow number of services per conception (SPC); number of days from calving to first service (CFS); number of days from calving to conception (DO); number of cows inseminated within 80 days post-partum (FS80d); number of cows confirmed pregnant within 100 days post-partum (PD100d) and number of cows confirmed pregnant within 200 days post-partum (PD200d)

Previously reported heritability estimates for AFS were 0.24 in Dutch Friesians (Jansen *et al.*, 1987), 0.12 in Canadian Holsteins (Raheja *et al.*, 1989), 0.22 in Ayrshire and Friesian cows (Mäntysaari *et al.*, 2002), 0.13 in Canadian Holstein heifers (Jamrozik *et al.*, 2005) and 0.10 to 0.64 for Holstein cows in different herds in Germany (Bergk, 2011). These estimates were higher than the 0.02 observed in this study. Heritability of AFC (0.08) was comparable to 0.09 obtained for the Kenyan Ayrshire (Amimo *et al.*, 2006) although higher than 0.03 reported for Iranian Holstein cows using animal model (Eghbalsaied, 2010) and lower than 0.13 obtained for multiple breeds of New Zealand using sire model (Grosshans *et al.*, 1997). The differences could be due to different statistical models used for analysis, varying reactions of the same breed to different environmental conditions or difference in farm management strategies. The reliability of the data analysed also influences the estimation of heritability. Age at first service is an economically important trait as it determines when an animal starts its reproductive life, and influencing the AFC, which has an impact on generational interval and response to selection as it is closely related to rearing intensity. Both traits influence the lifetime productivity of cows. However, using AFS and AFC as reproductive measures has limitations as the decision to start breeding may be purely managerial. In addition, AFC excludes heifers failing to conceive, already reducing available data for accurate genetic evaluations of breeding values.

The SPC was defined for both heifers and cows, and the variance components differed considerably. The heritability estimate of SPC in heifers was slightly lower (0.02) than in the corresponding cow trait (0.04). These estimates were consistent with previous

observations in US Holsteins, Canadian Holsteins, Brown Swiss and Chinese Holsteins (Hansen *et al.*, 1983; Jamrozik *et al.*, 2005; Tiezzi *et al.*, 2012; Liu *et al.*, 2017). The trait can be a good indicator of fertility as it tells the breeder whether a cow is fertile or not depending on the proficiency of the inseminator. Meanwhile, SPC is less dependent on management decisions in a viable dairy enterprise. Calving to first service and the number of days open had heritabilities of 0.06 and 0.05, respectively. Similar results were reported for Iranian Holsteins, Ireland Holstein-Friesian and Chinese Holsteins (Ghiasi *et al.*, 2011; Berry *et al.*, 2013; Liu *et al.*, 2017) but higher than 0.03 reported for both Tunisian and Chinese Holsteins (M'hamdi *et al.*, 2011; Guo *et al.*, 2014). On the contrary, higher heritabilities were reported for CFS (0.14) in Iranian Holsteins (Eghbalsaied, 2011). The current estimate for DO was similar to 0.05 and 0.07 reported for Chinese (Sun *et al.*, 2010) and Danish Holsteins, respectively (Guo *et al.*, 2014). However, higher heritabilities of 0.15 and 0.22, respectively, were reported for Ethiopian Holstein (Mohamed, 2004) and Holstein Friesian, (Yosef, 2006). Differences between the estimates of heritability observed in this study and estimates from other countries are most likely caused by different methods of estimation, management and environmental factors that affects genetic and environmental variances. The interaction between the environment and genetics (G×E) plays a significant role in the expression of an animal's full genetic merit in terms of performance (Rivas *et al.* 2006; Usman *et al.* 2013).

For binary traits, the observed heritability estimates ranged from low to moderate. The heritability estimate for first service within 80d post-partum was 0.07 and for the two binary traits indicating whether cows were confirmed pregnant within 100 or 200 days

post-partum were 0.13 and 0.24, respectively. However, Potgieter *et al.* (2011) observed lower heritability estimates ranging from 0.07 to 0.08 and 0.06 to 0.08 for both traits, respectively.

Results from this study were generally in agreement with previously reported estimates for fertility traits, which were relatively low heritability $< 10\%$ with the exception for binary traits. Heritability estimates of heifer traits were lower than estimates for cow traits excluding AFC. This can be attributable to the low genetic variances observed in the heifer traits SPCh and AFS. The relatively low heritability estimates observed in this study could be explained by environmental variances that are larger than the genetic variances. However, there is evidence of genetic basis in the analyzed fertility traits. Therefore, improvements in nutrition and reproductive management could be coupled with genetic selection to improve fertility in dairy herds.

4.4.2 Genetic and phenotypic correlations between heifer and cow fertility traits

Genetic and phenotypic correlations were estimated amongst the defined service based fertility traits. The genetic correlations between heifer traits were high and favourable, with the highest correlation between AFS and AFC (0.91 ± 0.01) being close to one. This indicates that AFC and AFS could be treated as the same trait due to one being heavily dependent on the other that they probably have the same physiological basis. These results were consistent with correlations of 0.98 and 0.99, respectively, reported by Jagusiak & Zarnecki (2006) and BrzÁková *et al.* (2019), respectively. Jamrozik *et al.* (2005) found a positive correlation between AFS and SPCh (0.28) although lower than in the current study. On the contrary, Guo *et al.*

(2014) reported a negative correlation between AFS and SPCh (-0.31). Variations in correlations in different countries may be due to different body conditions of heifers inseminated for the first time affecting their ability to conceive. High positive relationship observed between SPC, AFS and AFC indicates that younger cows conceive from fewer inseminations. Lower AFC positively affects genetic progress as generational interval decreases and it allows early progeny test of sampling bulls. Decreased AFC may be an efficient strategy for dairy farmers to reduce costs (Pirlo *et al.*, 2000). Heifer traits could be useful in fertility indexes as they are available early an animal's life.

Table 4.2 Genetic (above diagonal) and phenotypic (below diagonal) correlations between heifer and cow fertility traits of South African Holstein cattle.

Traits	AFS	AFC	SPCh	DO	CFS	SPC
AFS		0.91±0.01	0.73±0.00	0.62±0.00	0.36±0.03	0.84±0.00
AFC	0.89±0.00		0.69±0.00	0.63±0.01	0.73±0.01	0.95±0.00
SPCh	-0.06±0.01	0.28±0.01		0.48±0.00	0.73±0.00	0.05±0.01
CFS	0.12±0.01	0.11±0.01	0.03±0.01	0.42±0.01		0.90±0.01
DO	-0.03±0.02	-0.03±0.01	0.01±0.00		0.70±0.09	0.19±0.01
SPC	-0.13±0.02	-0.12±0.00	0.01±0.01	0.71±0.00	-0.15±0.00	

age at first service (AFS), age at first calving (AFC), number of services per conception for heifers (SPCh), number of days from calving to first service (CFS), number of days open (DO) and number of services per conception for cows (SPC)

Positive genetic correlations of 0.90, 0.19, and 0.70 were observed between cow fertility traits SPC and CFS, SPC and DO, CFS and DO, respectively. Although the correlation between SPC and DO was low (0.19), it was similar to the observation 0.21 reported by Zaabza *et al.* (2016). The estimate between SPC and CFS indicates that selection for shorter calving to first service will result in cows conceiving from fewer inseminations. De Haar *et al.* (2007) showed that cows that have good body condition

tend to have their first insemination early in lactation. The CFS had high positive correlation with DO, which was expected because they are partly regulated by the same physiological factors. CFS could be used to represent cow fertility in selection indexes as it is closely related to both SPC and DO indicating that fewer days between calving and first post-partum service results in fewer days open and the cow will conceive from fewer inseminations. The use of CFS instead of DO may minimize selection bias because using DO could exclude cows culled for not getting pregnant and CFS is available earlier than DO. Shortened CFS and DO means shorter calving intervals will lead to increased productivity due to cows completing more lactation periods. However, it should be shortened to the required biological level so as not to negatively affect the welfare of cows.

Genetic correlations between heifer and cow fertility traits were positive but the scale was wide (0.05 – 0.95). SPCh for heifers had the lowest correlation with SPC for cows (0.05) indicating that number of inseminations required for a heifer to conceive is not related to the number of insemination required for conception in cows. These results were in agreement with Raheja *et al.* (1989) who reported low genetic correlation between services per conception between heifers and cows (0.01). However, age at first service and age at first calving showed high positive genetic correlations with cow SPC (0.84 and 0.95). Thus, early sexual maturity has a positive effect on the number of services required for conception later in the animal's life. Genetic correlations between CFS and DO with all the heifer traits were moderate to high and positive (0.48 – 0.73). Previous literature reported moderate relationships between heifer and cow traits (Abe *et al.*, 2009; Mokhtari *et al.*, 2015). Phenotypic correlations between heifer and cow fertility traits were generally close to zero (-0.13 to 0.03). This indicates that

there is no phenotypic relationship between heifers and cows. Relationships among heifer traits were moderate to high and positive (0.28 to 0.89) with the exception of -0.06 between SPCh and AFS. Phenotypic correlations among cow fertility traits were high and positive (0.42 to 0.71) with the exception of the correlation between SPC and CFS (-0.15).

In this study, the genetic correlation of CFS with all the fertility traits was generally higher than the genetic correlations of DO with other fertility traits. The genetic relationship of heifer traits with cow traits indicates that heifer traits could be used in selection for improved fertility because these traits are available early in an animal's life. Jansen (1987) pointed out that using records of virgin heifers and first parity cows could be useful in genetic evaluations to obtain a sufficiently accurate sire evaluation. Janson (1980) found in Swedish Red and Whites that non-return rate (56 days) as well as number of inseminations per service period was highly correlated in virgin heifers and first parity cows. Furthermore, heifer fertility traits were observed to be closely associated with production traits (Abe *et al.*, 2009). Wathes *et al.* (2014) pointed out that aiming to rear replacement heifers to be bred at an early age (15 months) to calve at 24 months is optimum for economic performance as it reduces the non-productive period of cows while maintaining a seasonal calving pattern. This supports the current results that selection for early age at first insemination and age at first calving may be economically beneficially in dairy production. The estimated genetic correlations between fertility traits in heifers and cows were generally desirable, indicating that selection for improved fertility traits in heifers may improve reproductive performance during the animal's productive life.

Table 4.3 shows the genetic and phenotypic correlations between linear and binary traits. Estimates were negative ranging from -0.20 to -0.89 for genetic and -0.07 to -0.80 for phenotypic correlations, excluding a phenotypic correlation of 0.19 between SPC and FS80d. These correlations were generally favourable amongst the traits. Number of days open had the lowest genetic correlation with the number of cows being inseminated within 80 days post-partum (-0.20), although the relationship was favourable. Calving to first service had the highest favorable genetic relationship with FS80d (-0.89), indicating that selecting for a shorter interval from calving to first service a higher number of cows would be inseminated within 80 days post-partum and the cows will conceive from fewer inseminations as the genetic correlation between FS80d and SPC is also favorable (-0.46).

Table 4.3 Genetic and phenotypic correlations between linear cow and binary fertility traits using linear-binary multivariate analyses.

Linear Traits	Correlation Type	Binary Traits		
		FS80d	PD100d	PD200d
DO	Genetic	-0.20±0.00	-0.76±0.00	-0.85±0.00
	Phenotypic	-0.29±0.00	-0.07±0.00	-0.80±0.00
CFS	Genetic	-0.89±0.00	-0.27±0.00	-0.63±0.01
	Phenotypic	-0.71±0.00	-0.42±0.01	-0.25±0.01
SPC	Genetic	-0.46±0.00	-0.54±0.01	-0.57±0.01
	Phenotypic	0.19±0.00	-0.48±0.01	-0.58±0.01
FS80d	Genetic	-	0.39±0.01	0.47±0.01
	Phenotypic	-	0.37±0.01	0.12±0.01
PD100d	Genetic	0.39±0.01	-	-0.47±0.01
	Phenotypic	0.37±0.01	-	0.36±0.01

Number of services per conception for cows (SPC), number of days from calving to first service (CFS), number of days open (DO), whether cows were inseminated for the first time within 80 days post-partum (FS80d), whether cows were confirmed pregnant within 100 days post-partum (PD100d) and whether cows were confirmed pregnant within 200 days post-partum (PD200d).

The traits CFS, DO and SPC had favorable relationships with PD100d and PD200d, suggesting that decreasing the number of inseminations, shortening CFS and DO, more cows will be confirmed pregnant within 100 or 200 days post-partum which means a high percentage of cows will not exceed 200 days open. The genetic correlation between FS80d with PD100d and PD200d were positive and moderate (0.39 and 0.47), which demonstrates that when more inseminations occur within 80 days post-partum, more cows will be confirmed pregnant within 100 days or 200 days post-partum. However, PD100d and PD200d had a negative genetic relationship, which was expected because when a high percentage of cows are confirmed pregnant

within 100 days post-partum, a percentage of cows to be confirmed pregnant in 200 days post-partum will decrease.

4.5 CONCLUSION

Female fertility is a complex set of factors affected by genetic and environmental conditions. This study confirms that fertility traits generally presents low heritabilities (below 0.10) with the exception of binary traits, however, they have some genetic basis to warrant selection. Heifer and cow fertility traits should be treated as separate traits but genetically correlated and analyzed in a multiple trait manner. The high genetic correlations among the different fertility traits reveals the relationships amongst these traits, as predictions can be made on several fertility traits after performing selection on either one of the traits. Early availability of service data on fertility traits of heifers and the desirable genetic correlation with cow fertility traits presents an opportunity for these traits to be included in national genetic evaluations for Holstein cattle.

CHAPTER 5

Estimation of breeding values, genetic and phenotypic trends for service-based heifer and cow fertility traits of Holstein Cattle population

5.1 ABSTRACT

A total of 64 464 service-based fertility records were used to estimate genetic and phenotypic trends over the period 1984-2011 for heifer and cow fertility traits. The pedigree data consisted of information on 18 592 animals born between 1981 and 2013. A multivariate analysis was carried out using THRGIBBS1F90 and POSTGIBBSF90 of BLUPF90 family of programs (Misztal *et al.*, 2018) to obtain EBV's which were then averaged per birth year to get the genetic trends. The average breeding values for heifer traits did not show any particular trend. However, the phenotypic trends of heifer traits were showing a downward trend, with a decrease of 0.14 and 0.13 months/year for AFS and AFC, respectively. A decreasing trend of average breeding values of 0.003 per year was observed for heifer services per conception, although not significant ($P>0.05$). Average breeding values for cow fertility traits appeared to decrease for interval traits CFS and DO, excluding for SPC, which showed no distinct trend. Phenotypic trends for cow fertility traits appeared to be undesirable, with average increases of 0.16 and 0.83 days per year for CFS and DO, respectively and 0.02 more services per year for SPC. The average breeding values for binary traits were generally increasing. In general, average breeding values for all traits explored did not show any particular trend. Similarly, phenotypic trends were fluctuating over the period studied. This could mean that the breeders are not assessing the herd reproductive performance. Genetic and phenotypic trends that

appeared to follow trait improvement could have been coincidental. Thus, efforts have to be made towards the improvement of heifer and cow fertility traits in this study.

5.2 INTRODUCTION

The main goal of dairy producers is to increase milk yield and its composition. Until 1990s, the focal point of many dairy producing countries was to increase yields of milk, protein and fat (Miglior, 2005). This resulted in deterioration of overall fitness, including health and fertility because of the antagonistic association between fertility and milk yield (Van Arendonk *et al.*, 1989; Bagnato&Oltenacu, 1994; De Jong, 1998; Pryce *et al.*, 2004; Kadermideen, 2004; VanRaden *et al.*, 2004). However, the decreasing reproductive performance in dairy cattle has a negative impact on the profitability of a dairy herd (Britt, 1985; Dijkhuizen *et al.*, 1985), where high producing cows require more veterinary treatments and more AI services before conception i.e., increasing input costs of production thereby extending their days open and intercalving periods. Owing to its economic importance, producers moved towards more balanced breeding programmes, the objective of integrated health, longevity and fertility in addition to production (Miglior *et al.*, 2005).

In South Africa, genetic evaluations of fertility are based on age at first calving (AFC) and calving interval (CI) (Makgahlela *et al.*, 2008). Although this is a good step towards the improvement of fertility, Haile-Mariam *et al.* (2003) pointed out that cows that do not have subsequent calving dates or culled for not falling pregnant are excluded in genetic evaluations. This limits the potential use of CI as a measure of fertility in the

genetic evaluation of dairy cows, as information on the perceived least fertile group of cows is excluded, while AFC is problematic as it is highly influenced by the breeder's decision to start breeding. These drawbacks could lead to biases and inadequate information to generate accurate estimated breeding values for sires. Information on additional reproductive performance could be useful for inclusion in genetic evaluations. In any genetic improvement program, it is important to track the results and monitor the progress and effectiveness of a genetic selection program through evaluating the changes of genetic trends over time. A genetic trend is defined as a change in performance per unit of time due to change in mean breeding value (Canaza-Cayo *et al.*, 2016). A phenotypic trend is defined as a change in performance per unit time due to change in a phenotypic mean.

It is important for farmers to assess genetic trends in order to check whether the selection process is going in the intended direction ensuring the efficiency of their current selection procedure. Studies of genetic and phenotypic trends for fertility traits reported an increasing trend of 1.90, 1.25 and 1.34 days per year for calving interval in the South African Holstein population (Makgahlela *et al.*, 2008; Mostert *et al.*, 2010 & Ramatsoma *et al.*, 2014). The increasing trend of CI indicates a deterioration of post-partum fertility in the South African Holstein population. Evaluation of genetic progress will lead to establishment of future genetic direction by defining specific goals for breeding a profitable and sustainable dairy herd (Missanjo *et al.*, 2012).

The current study provides phenotypic and genetic trends for fertility measures derived from AI service records of the South African Holstein cattle, following the derived

genetic parameters of the traits in Chapter 4. Fertility traits are not commonly included in selection goals; however, they should also be monitored as they affect the profitability of a dairy herd, improvement of fertility can reduce production costs.

5.3. MATERIALS AND METHODS

5.3.1 Data

The same data set as was used for the estimation of genetic parameters was used to estimate breeding values following phenotypic and genetic trends. The data set consisted of artificial insemination records ($n=64464$) of heifers and cows which were collected from 18 South African Holstein herds using an on-farm automated milk recording system (DIMSSA). The pedigree consisted of information on 18592 animals born between 1981 and 2013. The data set included information on birth date, service and calving dates of each animal, lactation number of dam and sire identification numbers. The information was used to derive the analyzed traits (Table 3.1). The records were edited to remove outliers and further remove animals without birth years. The final dataset used for analysis is presented in Table 3.2.

5.3.2 Statistical analysis

The variance components estimated in Chapter 4 were subsequently used to estimate breeding values for fertility traits. Breeding values (EBV's) were estimated by adding the variances estimated from the first run of analyses for heritabilities and genetic correlations in to the parameter file, which was then used by THRGIBBS1F90 to run 100000 cycles with the first 10000 cycles discarded as burn in. Multivariate analysis

were run using the same models as described in Chapter 4. The EBV's were then used to determine genetic trends by calculating mean EBV's per birth year using dplyr package and plotted using ggplot2 package in the R CRAN (Wickham, 2016; Wicklam *et al.*, 2018). The phenotypic trends were estimated using average phenotypic values per birth year and visualized in R using ggplot2 (Wicklam, 2016).

5.4 RESULTS AND DISCUSSION

5.4.1 Results

Genetic and phenotypic trends of heifer, cow and binary fertility traits (Figure 5.1-5.9)

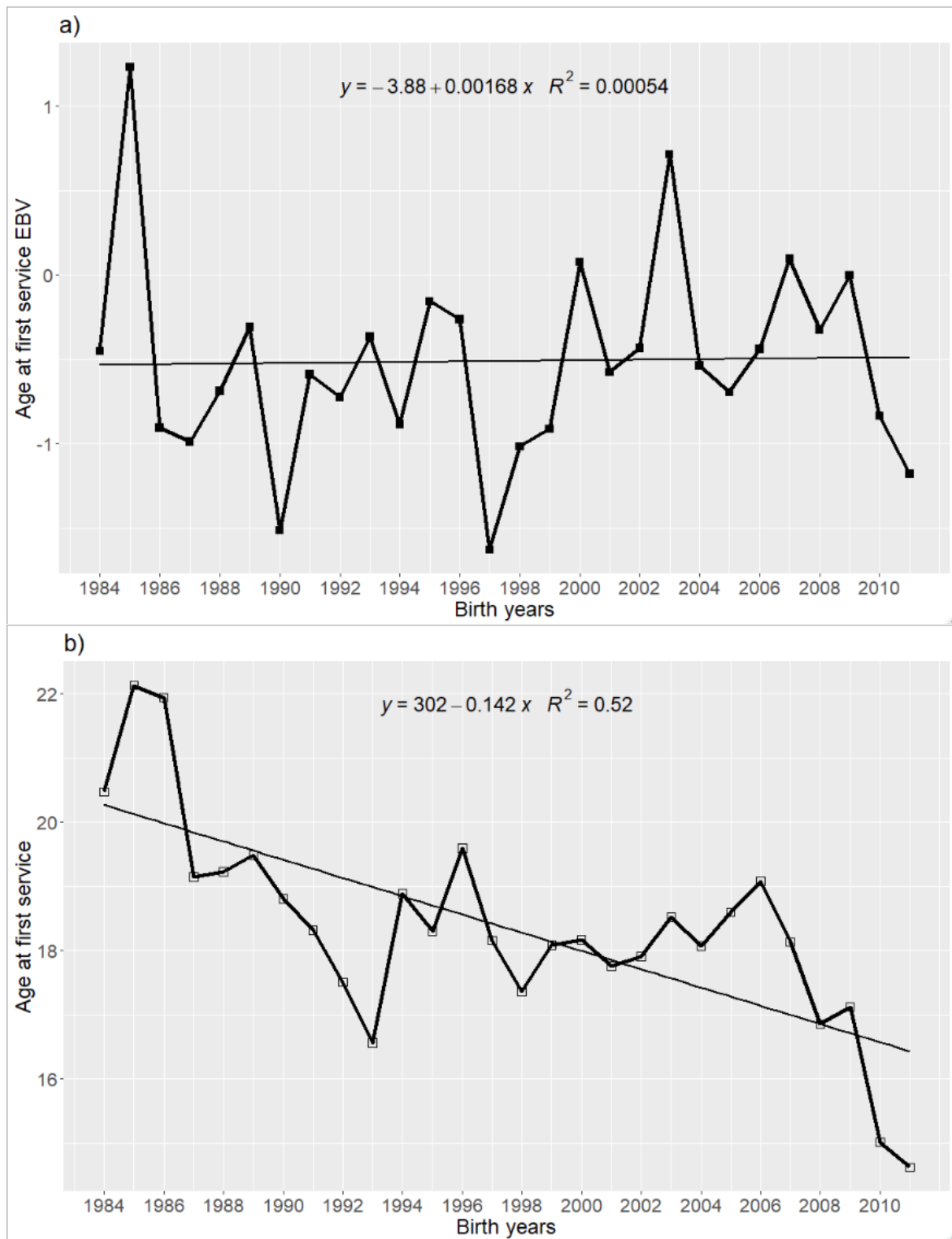


Figure 5.1. The genetic (a) and phenotypic (b) trends for AFS.

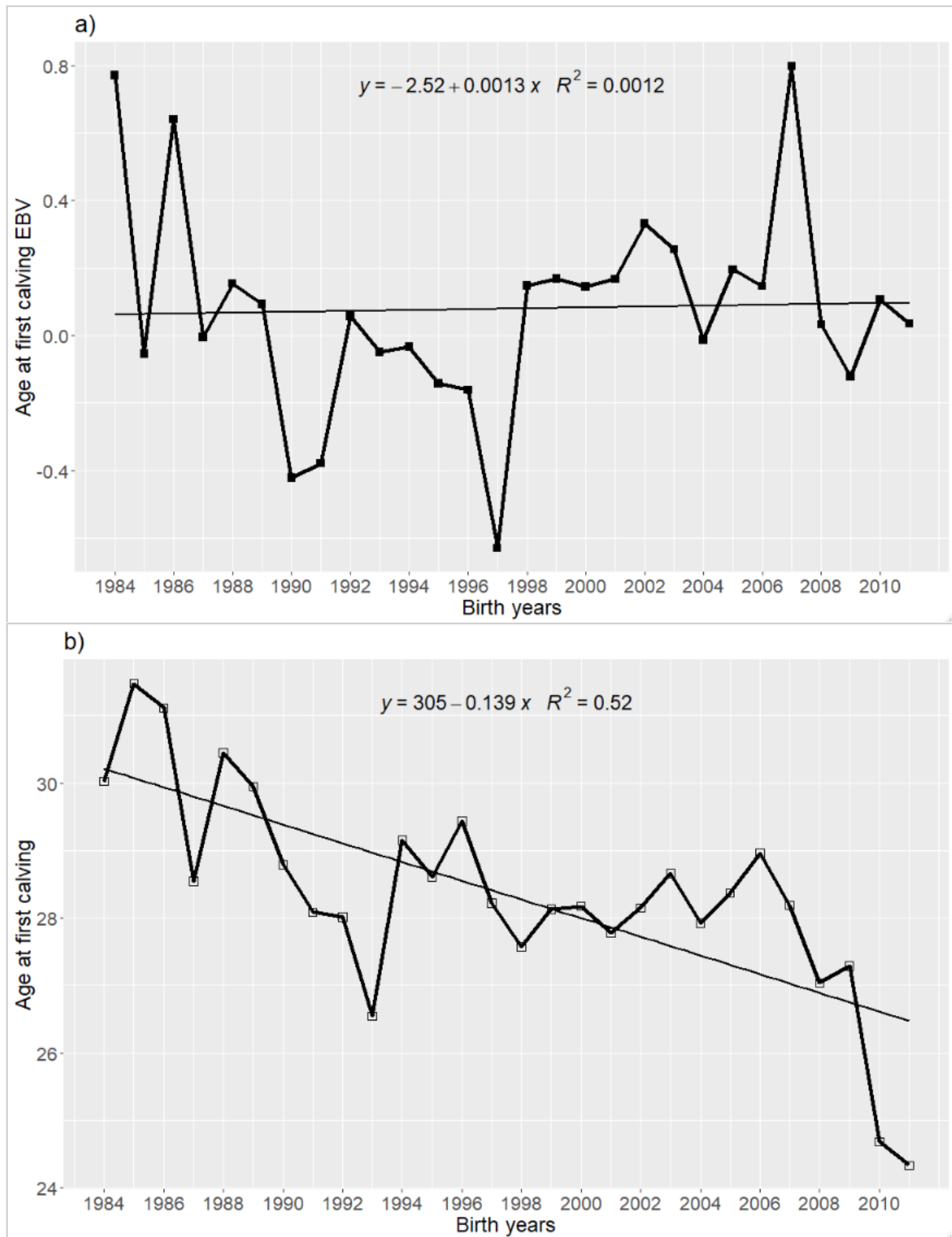


Figure 5.2. The genetic (a) and phenotypic (b) trends for AFC.

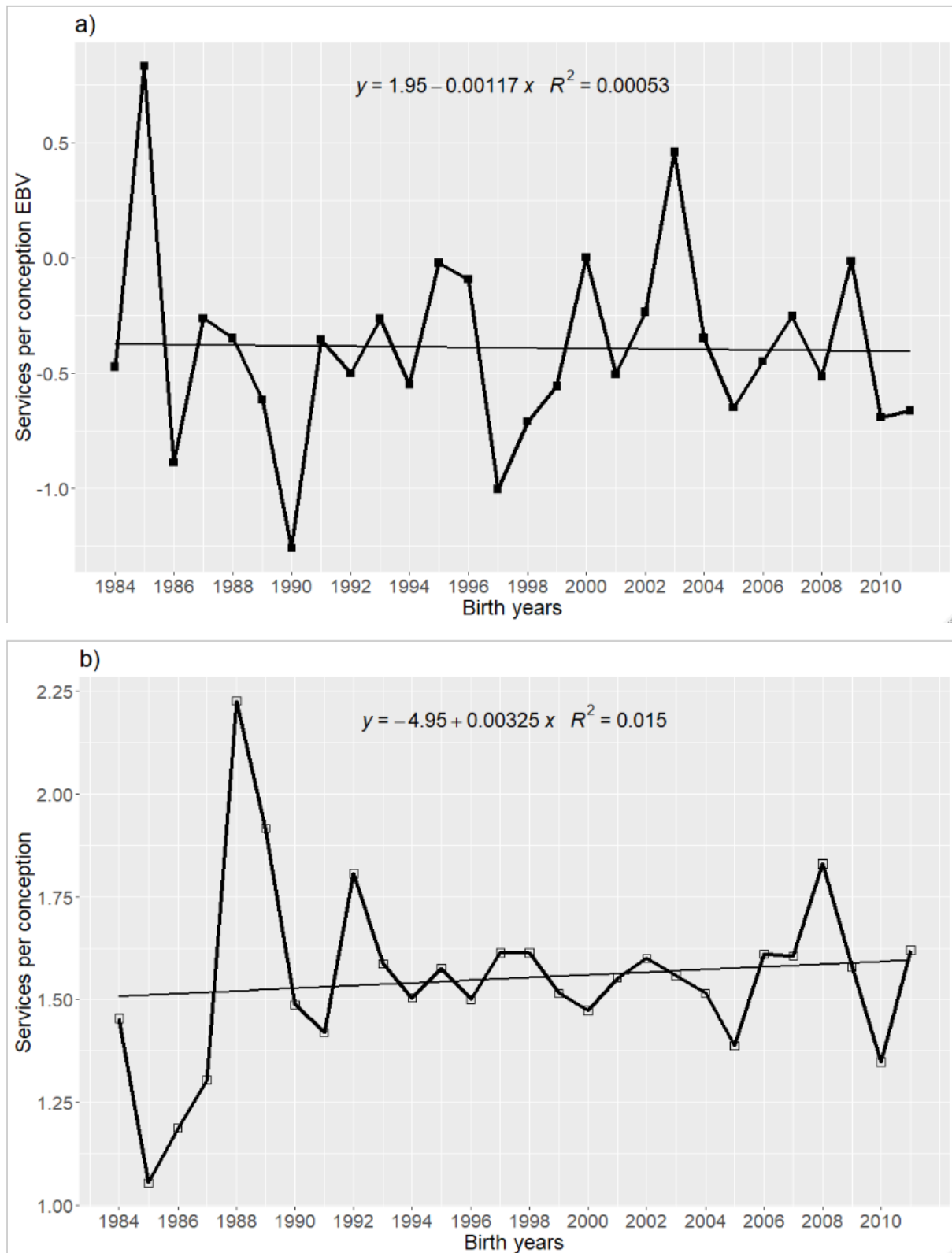


Figure 5.3. The genetic (a) and phenotypic (b) trends for SPCh.

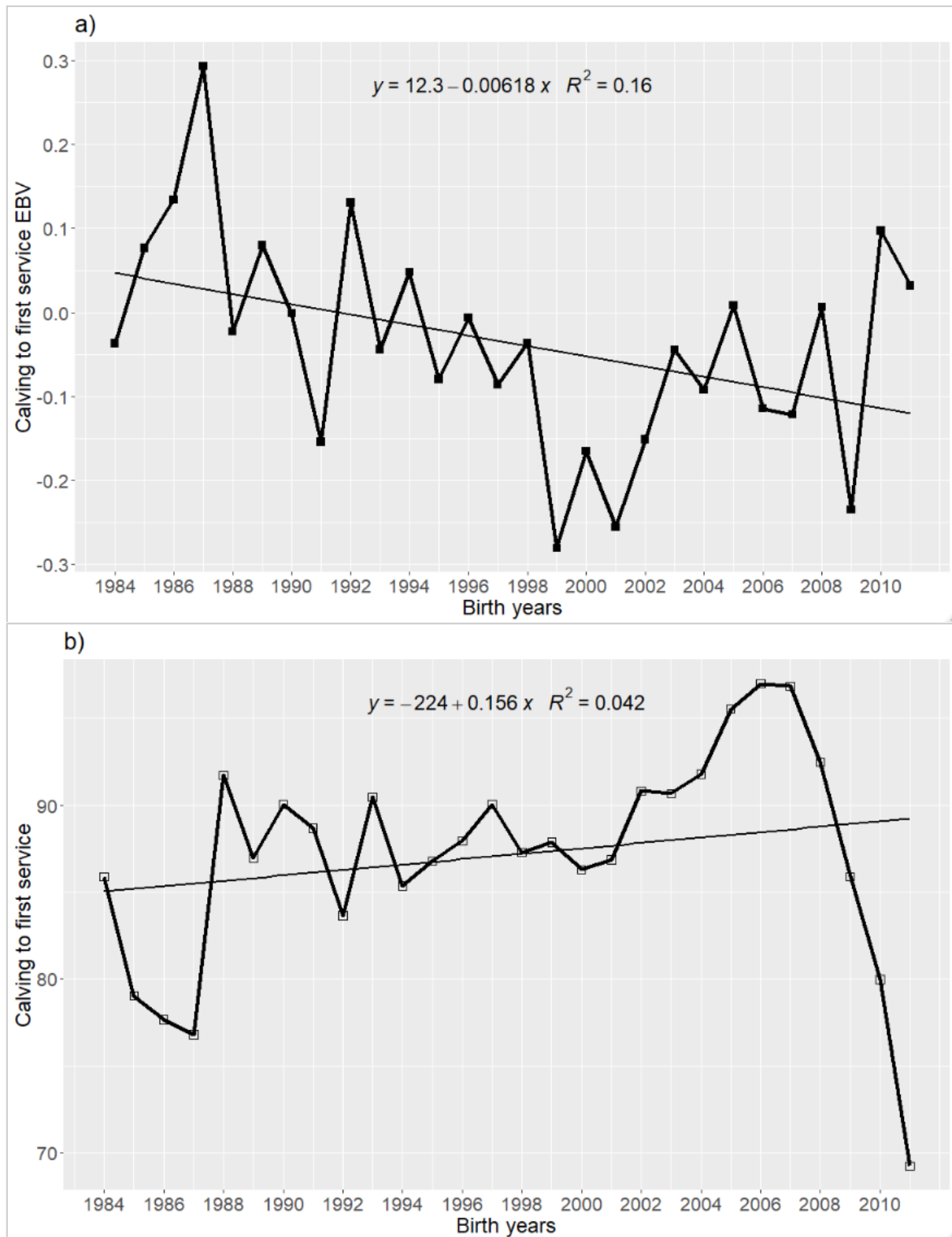


Figure 5.4. The genetic (a) and phenotypic (b) trends for CFS.

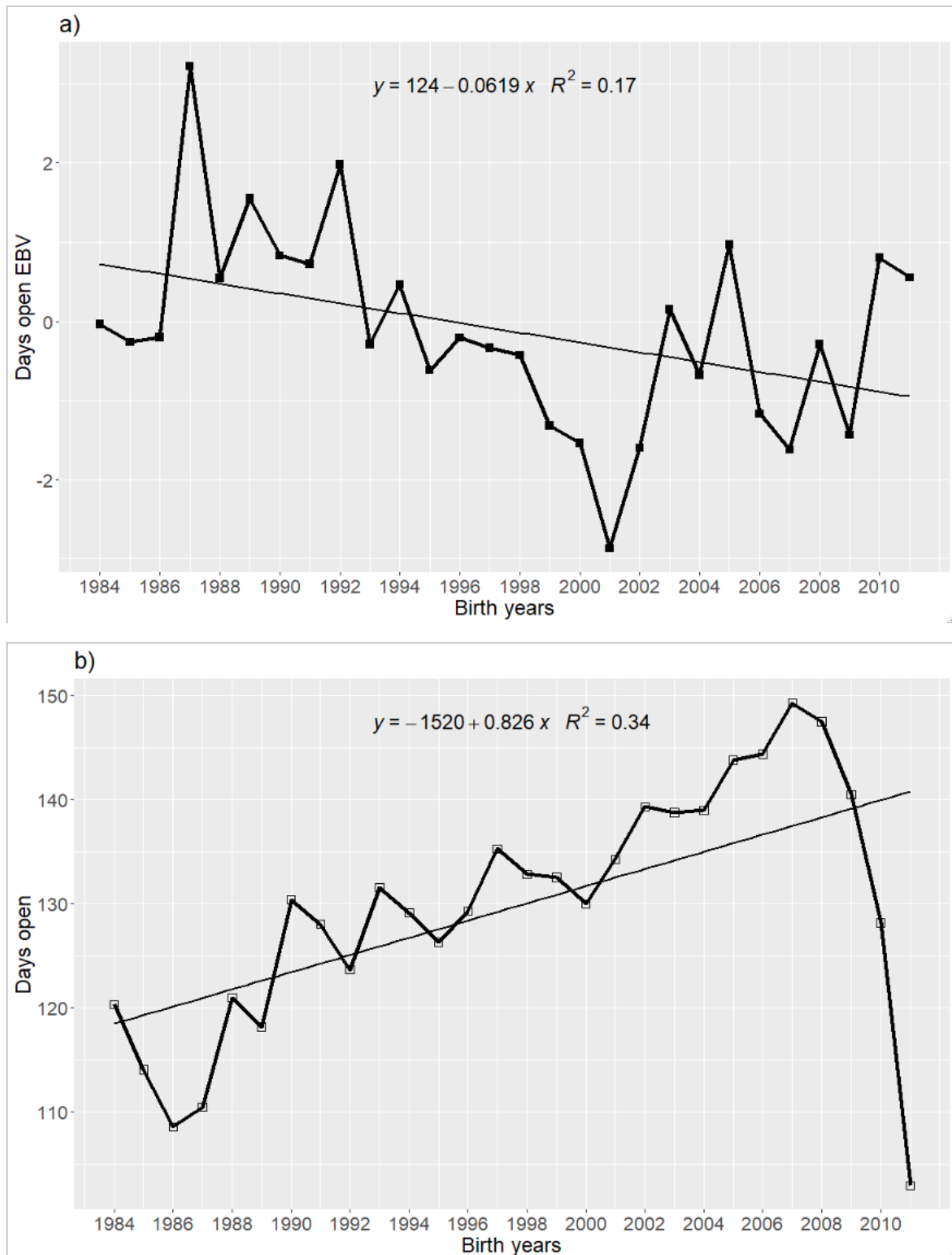


Figure 5.5. The genetic (a) and phenotypic (b) trends for DO.

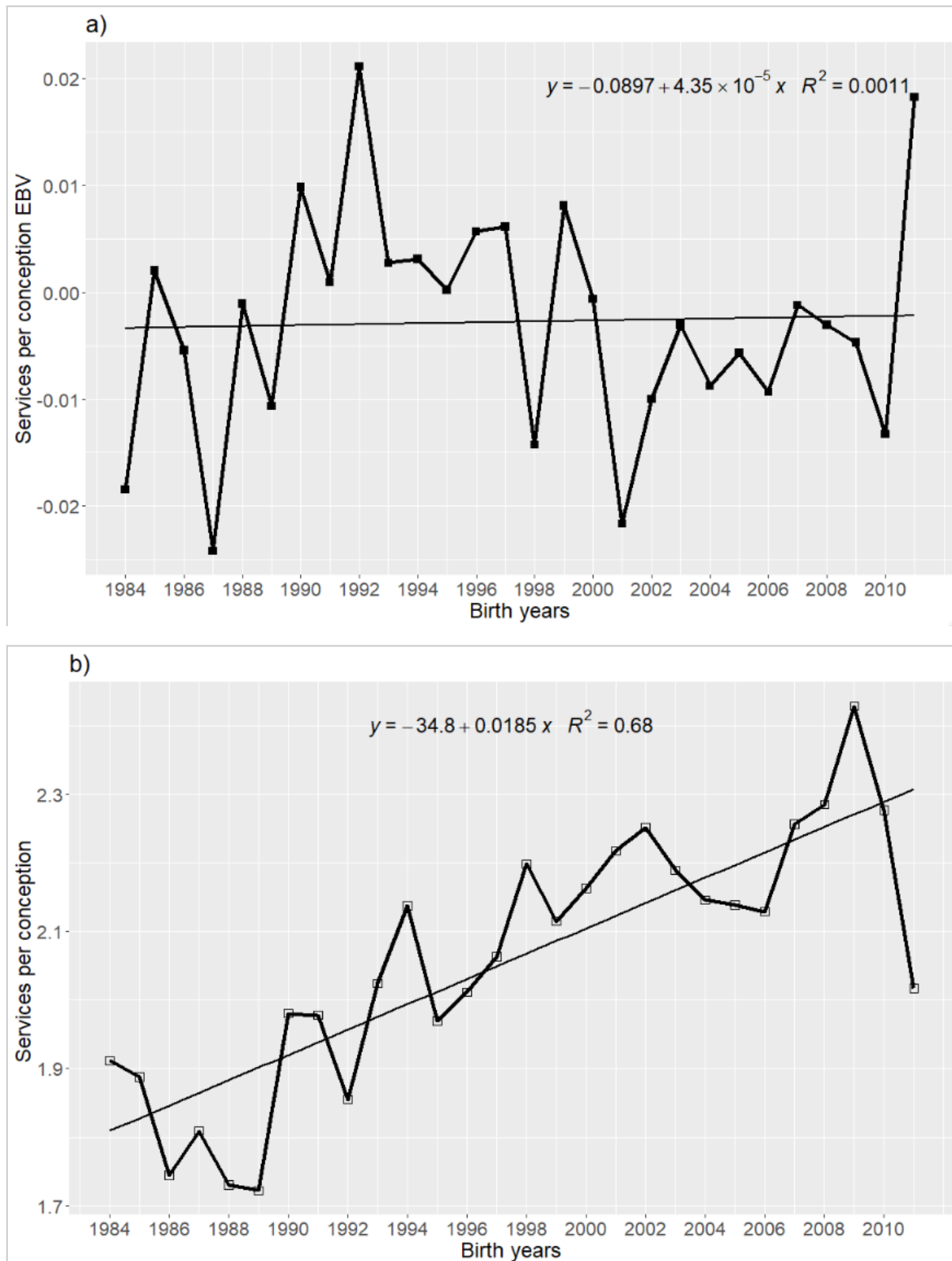


Figure 5.6. The genetic (a) and phenotypic (b) trends for SPC.

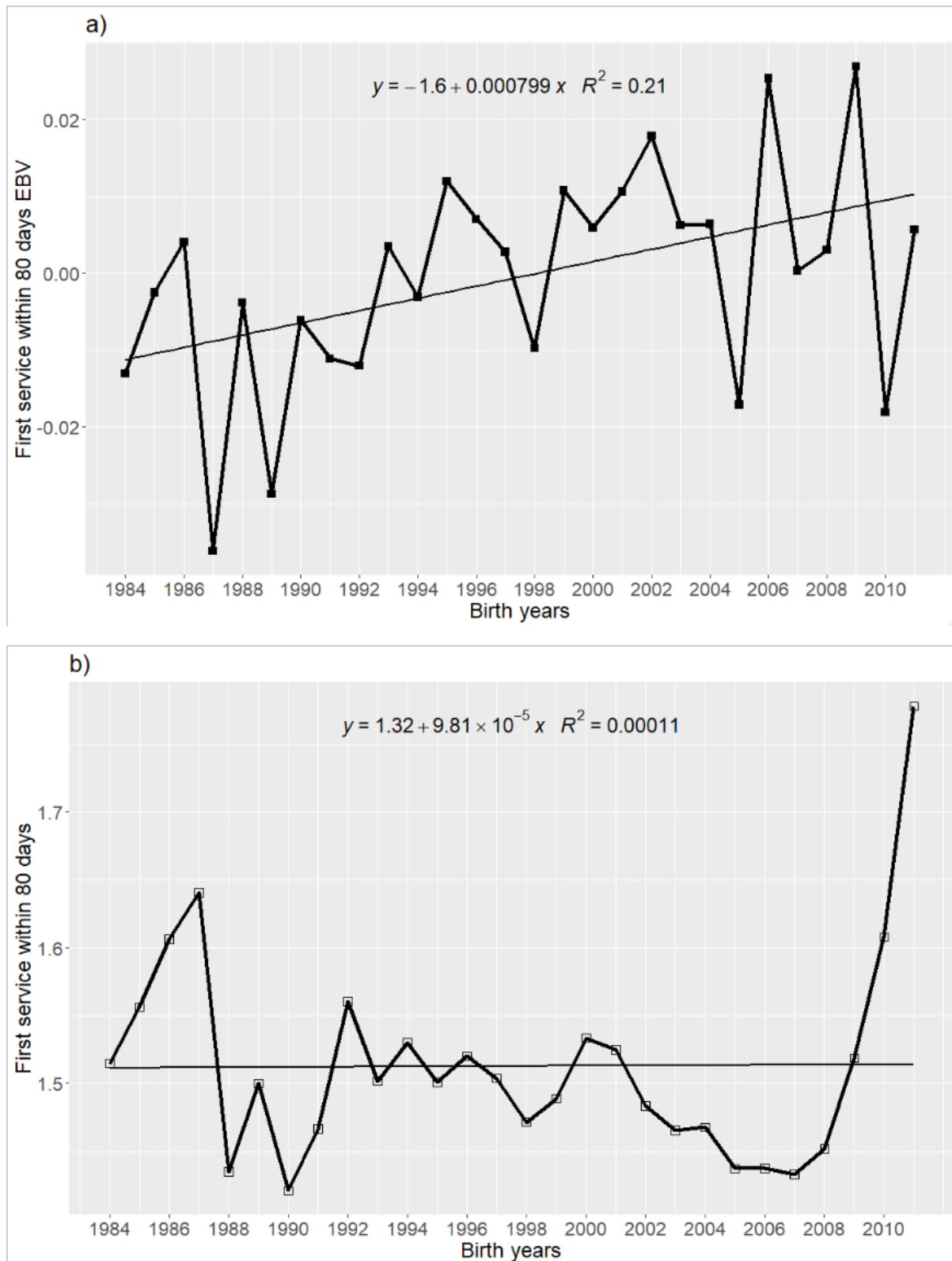


Figure 5.7. The genetic (a) and phenotypic (b) trends for FS80d.

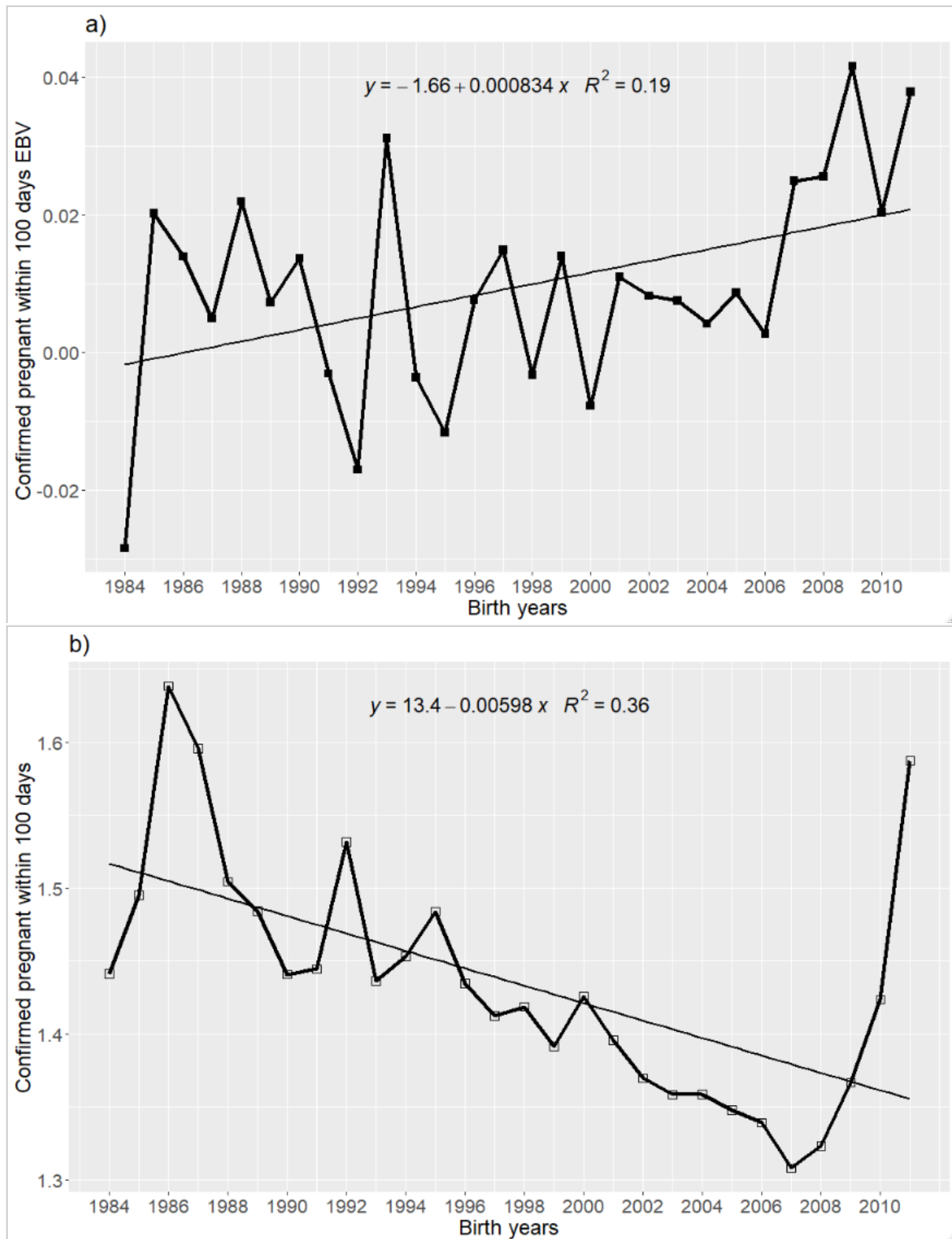


Figure 5.8. The genetic (a) and phenotypic (b) trends for PD100d.

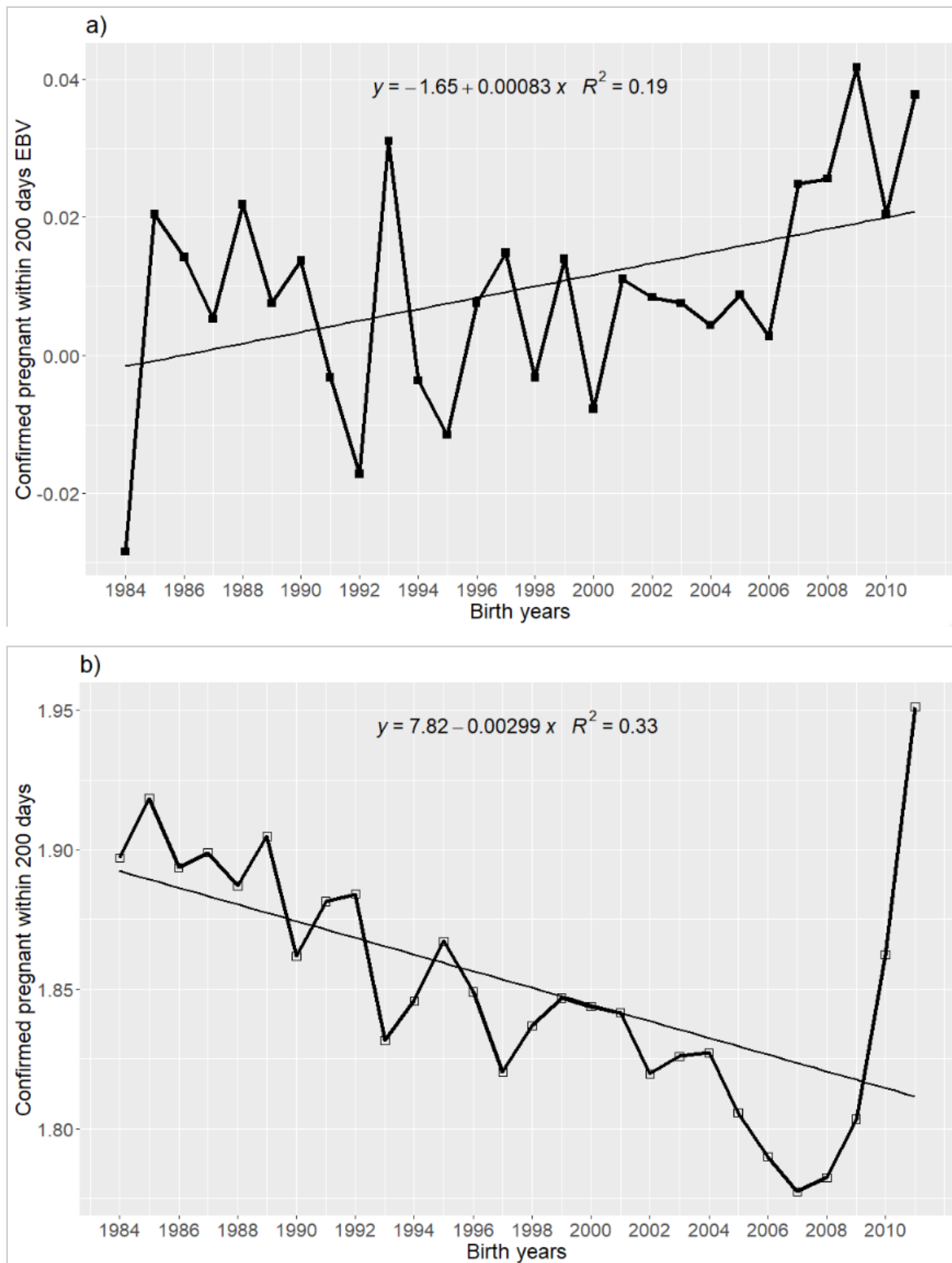


Figure 5.9. The genetic (a) and phenotypic (b) trends for PD200d.

5.4.2 Discussion

5.4.2.1 Heifer phenotypic and genetic trends for South African Holstein cattle population

The primary focus of breeding programs in South Africa has been on increased milk production (Banga & Rautenbach, 1999). This may cause little to no improvement in fertility traits of South African dairy cattle. Figure 5.1 shows the genetic (a) and phenotypic (b) trends of age at first service (AFS) for South African Holstein cattle. The average EBV of AFS over the years shows no particular trend. This may be because genetic selection for lower AFS is not highly practiced in South Africa as the decision on when to inseminate is mostly managerial. The mean EBV shows a dramatic increase from 1984(-0.45) to 1985 (1.22) then decrease to -0.90 in 1986. In most years the mean EBV was on the negative side with the lowest being (-1.51,-1.63 and -1.18) in (1990, 1997 and 2011) respectively. The average EBV shows that not much has been done in improving AFS genetically in the past years.

The phenotypic trend of AFS generally shows a decrease in the average mean over the years. There has been a slight decrease of 1month/year from 1984 to 1993, and then there was an annual increase of 2months from 1993 to 1994. The decreasing trend continued from 1996 to 2011. The average decrease of (-0.14 months/year) was observed over the years for the phenotypic trend. The phenotypic decrease of age at first calving was desirable, this could be due to management decisions of breeding animals early. The decreasing trend might also be representing early maturity from better calf rearing, good nutrition and management.

The genetic (a) and phenotypic (b) trends of age at first calving (AFC) are shown in Figure 5.2. The average EBV for AFC shows no distinct trend. There was a decrease in average EBV from 1988 to 1997 then an increase from 1997 to 2002. Followed by a decrease from 2002 to 2004 however the mean EBV shot up from 2006 to 2007, although that was followed by a visible decrease from 2007 to 2009. The general trend for AFC was negative (-2.52) and non-significant ($P>0.05$) for the South African Holstein breed, indicating that there was no genetic improvement of AFC for the period 19884 to 2011. Makgahlela *et al.* (2008) reported a decrease in the trend of AFC for the same South African breed. Chawala *et al.* (2017) also reported a negative trend for AFC.

The phenotypic trend of AFC is shown in Figure 5.2(b), which shows a general decrease of AFC over the years. Although the trend started with the annual increase of average AFC from 1984 to 1985, however, a decrease is visible from 1988 to 1993 then there was a slight increase from 1993 to 1996. The phenotypic trend however continued to decrease from 1996 to 2011. There is an overall decrease in the phenotypic trend of AFC (-0.13.days/year). The decrease of AFC over the years may be due to breeders deciding to breed animals' early, good nutrition, favorable environmental conditions and good management strategies may have contributed to the decline of AFC.

Figure 5.3 shows the genetic (a) and phenotypic (b) trends for heifer number of services per conception (SPCh). There was no distinct trend for SPCh. The average EBV decreased from 1986 to 1997 although followed by a slight increase from 1997 to 2003. However, the trend continued to decrease from 2003 to 2011. The slope was

negative (-0.001) although close to zero and statistically not significant indicating that there is no genetic improvement for heifer services per conception. There was no distinct phenotypic trend for SPCh and the slope was close to zero (0.003). There was a visible increase of the average SPC from 1985 to 1988 and it was almost constant from 1994 to 2004, however, decreased from 2004 to 2008. The non-significant genetic and phenotypic trends for number of services per conception in heifers show that there has been no improvement of this fertility trait genetically and phenotypically from 1984 to 2011. The average EBV in all the heifer fertility traits shows no distinct trend indicating that heifer fertility traits have not been improving over the years.

5.4.2.2 Genetic and phenotypic trends for cow and binary fertility traits in the South African Holstein cattle population.

The genetic and phenotypic trends for cow traits, together with the binary traits are presented on Figure 5.4 to 5.9. The average EBV (5.4 a) of CFS shows a decreasing trend over the period 1984 to 2011. The genetic trend of CFS is going in a favorable direction although the decrease was very close to zero (-0.01) days/year. The current results are in agreement with the results reported by Ghiasi *et al* (2016), whom reported a decrease of (-0.062) days/year for interval to first service. This genetic trend indicates that there is a genetic potential for reducing CFS following a selection in the direction favoring the trait.

Figure 5.4(b) shows an increasing in days to first service from the year 1987 to 2007; however, there was a visible decrease from 2007 to 2011. The overall phenotypic trend of CFS was unfavorable with an increase of 0.16days/year. The unfavourable

phenotypic trend can be counter-acted by the favorable genetic trend of CFS that shows the ability of cows to recycle post-partum, if efforts can be made to improve the trait through genetic selection.

The average EBV for Days open shows a decrease of (-0.06) days per year. Ghiansi *et al* (2016) reported a decrease of (-0.24 days/year) in Iranian Holstein cows. The decreasing genetic trend for DO was desirable and statistically significant ($P < 0.05$). Although average increases of calving interval (CI), a fertility trait closely related to DO have been reported (1.9, 1.25 and 1.34 days per year) by Makgahlela *et al.* (2008), Mostert *et al.* (2010) and Ramatsoma *et al.* (2014), respectively in the South African Holstein cattle. The two traits DO and CI are reported to be highly correlated 0.99 (Eghbalsaied, 2011; Brzáková *et al.*, 2019) indicating that they have the same physiological base. However, studies reported that DO should be preferred over, CI in breeding programs for higher genetic progress because DO has higher heritability and genetic variance than CI (Silva *et al.*, 1992; Brzáková *et al.*, 2019). This approach may be beneficial; an improvement in DO may lead to a correlated improvement in CI.

The phenotypic trend (Figure 5.5 b) shows an overall increase in the number of days open over the years. There was an increase in the average days open from 1986 to 2007, which shows an overall increasing trend for the trait over two decades. Although there was a decrease from 2007 to 2011. The overall phenotypic trend for DO was unfavorable and highly significant ($P < 0.001$) showing an increase of (0.83 days/year).

The genetic and phenotypic trend for cow services per conception (SPC) are shown in Figure 5.6 a) and b) respectively. The slope of regression for SPC was close to zero (0.00004) and statistically not significant ($P>0.05$), indicating no distinct genetic trend for SPC. This is similar to heifers indicating that there has been no significant genetic change in the number of services required for conception in both heifers and cows. However, Figure 5.6 b) shows an unfavorable phenotypic trend of SPC with an average increase of 0.02 per year, indicating that over the years cows required more services for successful conception.

The genetic and phenotypic trends for the binary traits are shown from Figure 5.7 to 5.9. The average EBV for whether the first service was performed within 80 days post-partum (FS80d) was generally increasing although the increase was significant ($P<0.05$), the rate of increase was close to zero (0.0001). The phenotypic means for FS80d (Figure 5.7 b) shows no distinct trend, indicating that there has not been much change over the years in the number of cows returning to service within 80 days post-partum. The genetic trend of cows confirmed pregnant within 100days post-partum (Figure 5.8a) was increasing although similar to the genetic trend of FS80d, the rate of increase was very slow (0.0008). The phenotypic trend of PD100d was decreasing (-0.005) per year indicating that most cows were confirmed pregnant later than 100days post-partum. The genetic trend of cows confirmed pregnant within 200 days post-partum was increasing at the rate of (0.0008) indicating that there is a genetic increase of cows being confirmed pregnant within 200 days post-partum. The variable increase in the average EBV's of PD200 is visible from 1992 to 2011. However, the phenotypic trend for PD200d was decreasing at a rate of (-0.003). The variable

decrease is visible from 1984 to 2004 indicating that phenotypically the number of cows being confirmed pregnant was decreasing over the years. In general, the average EBV of the binary traits were increase although at a very slow rate.

5.5 CONCLUSION

The average EBV for heifer traits showed no distinct trend while for cow traits there were some observed favorable trends but of a small magnitude. Favorable phenotypic trends were observed for heifer fertility traits although this may not lead to an improvement in heifer fertility performance due to the overall undesirable genetic trends, the phenotypic improvement might have been from good management and environmental conditions while the problem still lies genetically. Generally, the average breeding values for heifer and cow fertility traits were not desirable indicating that an intervention is required to improve the reproductive performance of South African Holstein dairy cattle.

CHAPTER 6

General conclusions and recommendations

The main objective of dairy farmers is to increase milk production at a lowest possible input cost; hence, previously the focal point of selection programs was to increase milk yield and its components, as they are the produced commodity. However, fertility is a trait of outstanding economic importance in dairy cattle and it is increasingly being incorporated in national dairy cattle breeding objectives worldwide. Lack of proper data recording is one of the factors hampering the incorporation of fertility in genetic evaluations as it causes lack of breeding values and a slow genetic improvement of the trait. In South Africa, calving interval and age at first calving are used as indicator traits for genetic evaluations of fertility because the information is available on National Milk Recording Scheme database. These traits presents some limitations as they are heavily influenced by management decisions and calving interval depends on subsequent calving dates and cows not becoming pregnant are culled and excluded from genetic evaluations which may lead to selection bias or over estimation of the overall herd reproductive performance.

Calving interval is a result of successive events that can be defined and used separately or in combination as fertility indicators. Such traits are not routinely recorded on the national milk recording scheme but are kept on farm for management purposes. In this study, additional reproductive measures were defined from on-farm service records and genetic parameters, correlations and trends were estimated. The traits included the following: age at first service, age at first calving, interval from calving to first service, number of days open, number of services per conception for

heifers and cows, whether cows were inseminated within 80 days post-partum, whether cows were confirmed pregnant within 100 or 200 days. The tested non-genetic factors including herd, year, season, lactation number and calving age significantly affected these fertility traits. All significant non-genetic factors were then included in the linear mixed models for the estimation of genetic parameters and the genetic evaluation of estimated breeding values. The heritability estimates of the traits ranged from 0.02 ± 0.04 to 0.24 ± 0.00 indicating that there is genetic aspects for the traits, which is an opportunity for genetic improvement through selection. The variance component estimates of these traits obtained in the current study form the basis for routine genetic evaluations of heifer and cow fertility in the South African Holstein population on a broader scope.

The heifer traits age at first service and number of services per conception are available early in the animal's life and could be used in addition to age at first calving as fertility indicators in genetic evaluations of South African Holstein cattle population. High positive genetic relationship observed between SPC, AFS and AFC indicates that younger cows conceive from fewer inseminations. Lower AFS and AFC positively affects genetic progress as generational interval decreases and it allows early progeny test of sampling bulls, decreased AFS and AFC may be an efficient strategy for dairy farmers to reduce costs (Pirlo *et al.*, 2000). Heifer traits could be useful in fertility indexes as they are available early an animal's life and are positively correlated with cow traits. The desirable improvement of heifer fertility performance could lead to a favorable reproductive performance for cows. The trait calving to first service has a favorable genetic relationship with number of services per conception and number of days open and has a heritability that is slightly higher than both traits. Thus making it

a desirable trait for genetic improvement of fertility. The use of CFS instead of DO may minimize selection bias because using DO could exclude cows culled for not getting pregnant and CFS is available earlier than DO. Shortened CFS and DO means shorter calving intervals will lead to increased productivity due to cows completing more lactation periods.

The phenotypic and genetic trends estimated for the fertility traits of South African Holstein cattle, in this study are generally undesirable. Thus, an urgent intervention is required to improve the current state of fertility in South African Holstein dairy herds through selection. Artificial insemination records provides an opportunity for inclusion of additional fertility traits in genetic evaluations and potentially in the breeding objectives of South Holstein dairy cattle population. Therefore, farmers are encouraged to record such information and make it available for genetic evaluations in the quest to improve reproductive performance of South African dairy herds.

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